ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. XIV NOVEMBER, 1919 No. 7

MAGNETIC IRON ORES OF CLINTON COUNTY, NEW YORK.[1]

WILLIAM J. MILLER.

INTRODUCTION.

The magnetic iron ore deposits considered in this paper lie in the middle western portion of Clinton County, New York, from 15 to 25 miles west of Plattsburg. They are all within the Lyon Mountain quadrangle which covers an area of Precambrian rocks at the northeastern border of the Adirondack region. The Arnold Hill and Palmer Hill mines in the southeastern portion of the county are not discussed. At present the mining operations are confined to the so-called "main workings" at Lyon Mountain village which are a part of a property owned by the Chateaugay Ore and Iron Company. This property includes a general belt of ore deposits reaching from the Standish mine about 2½ miles southwest of Lyon Mountain village, through the Phillips ore body, the main workings, Williams mine, and to the Parker mine about 2½ miles northeast of the village. All except the Phillips ore body have been rather extensively worked, the total production of ore since 1871 having been probably about 5,000,000 tons. These ores have always found a ready market because of their high grade Bessemer quality.

The second most important ore belt lies in the Saranac valley, extending nearly east-west for about six miles from north of

[1] Published by permission of the State Geologist of New York.

Riverview to south of Redford. A number of mines have been operated within this belt, but none for many years. Most important are the Tremblay mines near Riverview, the Clayburg mines, and the Bowen and Signor mines one mile south of Redford, the last named having yielded about 260,000 tons of ore. Several small mines occur at and near Russia Station, and small mines and prospects have been opened at various other localities.

It is the present purpose to emphasize only those features which have a direct bearing upon the problems of the structure and origin of the iron ores. Many other data regarding the mines of the district may be found in Newland's "Geology of the Adirondack Magnetic Iron Ores."[2] The writer gratefully acknowledges his indebtedness to Mr. Newland for this valuable work.

To Mr. George E. Bent, manager of the Chateaugay Ore and Iron Company, the writer feels under special obligation not only for being allowed the freedom of the mines, but also for direct interest and aid in the work.

ROCKS OF THE REGION.

The rocks of the region under consideration are all of Precambrian age, the oldest belonging to the Grenville series which is unusually scantily represented. The Grenville rocks are mostly quartzites, schists, and gneisses which are in the form of a few very small remnants of a once widespread series of strata badly cut to pieces by the intrusives below mentioned. These rocks are of no special importance in connection with the structure and origin of the iron ores.

Gabbro and Hornblende Gneiss.—So far as known, the next oldest rocks are gabbro and hornblende gneiss or amphibolite. Much of the gabbro, which usually has an ophitic texture and is very massive, is clearly older than the granites of the region and younger than the Grenville as shown by the field relations. Some of the gabbro may, as is well known for the Adirondack region

[2] D. H. Newland, N. Y. State Mus. Bul. 119, 1908, especially pp. 23–36 and 105–128.

in general, be younger than the syenite-granite series, but no positive proof for such younger gabbro was obtained by the writer. In many cases the true gabbro grades into hornblende gneiss or even amphibolite. But it is by no means certain that all the hornblende gneiss and amphibolite of the district are facies of the old gabbro. Some may be younger, and some may possibly represent metamorphosed portions of the Grenville sedimentary series.

A thin section of the typical non-foliated gabbro, whose composition is unaffected by granitic or pegmatitic intrusions, shows the following mineral percentages: labradorite, 45; hornblende, 30; hypersthene, 21; magnetite, 3; biotite, ½; pyrite, ½; and a very little zircon and apatite. Many of the foliated facies of the gabbro practically duplicate this in composition, while still others are typified by a thin section showing: andesine to labradorite, 46; hornblende, 50; magnetite, 4; biotite, 1; pyrite, ½; and apatite, ½. Some hornblende gneisses and amphibolites not definitely known to be facies of the gabbro show compositions very much like those just given. Whatever doubt there may be regarding the gabbro and hornblende gneisses, the important facts concerning the present discussion are that most of them at least are older than the granites of the region, and that they are iron-rich rocks.

Anorthosite.—Anorthosite, which is younger than the Grenville and older than the syenite-granite series, occurs in several small areas, but it is of no special importance in the present discussion.

Granitic Rocks.—Several varieties of granite and granitic syenite constitute the main bulk of the rocks of the Lyon Mountain district. Among these the variety of chief interest in this paper is a fine to medium grained, usually pink, rock locally varying from a true granite through granitic syenite to quartz syenite or even quartz diorite. In the more typical specimens of the granite, dark minerals, except magnetite, are either almost wholly absent or they make up less than 6 or 7 per cent. of the rock. Thin sections of the typical granites contain microperthite, 45 to 70 per

cent.; quartz, 25 to 35 per cent.; oligoclase, 5 to 25 per cent.; usually microcline, 5 to 25 per cent.; magnetite, ½ to 2 per cent.; and usually less than 5 per cent. of the following: titanite, hornblende or pyroxene, biotite, zircon, apatite and hematite (stains). Locally, probably due to incorporation of material from the older basic rocks, dark minerals, including hornblende, monoclinic pyroxene (diallage), and biotite, are fairly conspicuous. A magmatic flow-structure foliation is generally more or less well developed in the granite, but some portions of the rock which are almost free from dark minerals exhibit practically no foliation to the naked eye. The writer has called this rock the "Lyon Mountain granite" because of its excellent exposures in and near Lyon Mountain village. The rock is also extensively developed on Johnson Mountain, Duncan Mountain, and in the valley of the Saranac River. The Lyon Mountain granite contains a truly wonderful display of pegmatite and silexite (see below). In many places the granite is very highly pegmatized. All the magnetic iron ore deposits of the quadrangle are directly associated with this granite.

There is considerable field evidence to show that the Lyon Mountain granite grades into, and is only a facies of, a coarse-grained rock which the writer has called the "Hawkeye granite," because of its excellent exposures in the vicinity of Hawkeye village. In thin section the rock from the type locality shows microcline, microperthite, and quartz in about equal amounts; 8 to 10 per cent. of oligoclase to albite; and small quantities of biotite, apatite, zircon, magnetite, chlorite, and secondary calcite. At the summit of Lyon Mountain the rock contains 2 or 3 per cent. each of hornblende, diallage, and bronzite. The feldspar and quartz crystals are usually from one fourth of an inch to one inch long. Where fresh the rock is greenish-gray. It weathers to a light brown. A gneissoid structure is generally more or less well developed, though considerable bodies of the rock show it scarcely at all. This Hawkeye granite is extensively developed in the Lyon Mountain quadrangle, being especially conspicuous in Silver Lake Mountain and in the southeastern half of the great

mass of Lyon Mountain. This granite contains relatively few pegmatites and silexites, and, so far as known, magnetic iron ore deposits do not occur in it.

Dikes and Pegmatites.—Special mention should be made of the dikes and other masses of pegmatite and silexite and dikes of aplite which, in age and origin, are closely associated with the granites.[3] The Lyon Mountain granite contains a great profusion of pegmatite and silexite masses and no aplite dikes, while the Hawkeye granite contains many aplite dikes and relatively few pegmatite and silexite masses.[4] Most of the pegmatites by far consist almost wholly of quartz and alkalic feldspar, and, with a few local exceptions, minerals which indicate the former presence of mineralizers other than water vapor are practically absent. The relations of pegmatite and silexite masses to the enclosing granite make it clear that they both began to develop, probably as segregation masses, while the granite magma still possessed a considerable degree of fluidity and that they continued to form, probably both as segregation products and as dikes, until the enclosing granite almost or possibly completely solidified. The silexite masses represent very siliceous facies of the pegmatitic development, graduations from nearly pure silica to ordinary pegmatite being not uncommon. Most of the pegmatite, silexite and aplite by far occur within the parent granites, though some also occur in the remnants of the old rocks which were intruded by the granites. As explained beyond, the pegmatites and silexites are of great importance in the consideration of the origin of the magnetic iron ores, the ore bodies really being highly pegmatized zones of the Lyon Mountain granite rich in magnetite.

In many places the older rocks, including the Grenville series, gabbro, and hornblende gneisses (or amphibolites), have been more or less injected or assimilated by the Lyon Mountain

[3] The term "silexite" has recently been proposed by the writer (*Science*, Vol. 49, 1919, p. 149) for any body of pure or nearly pure silica of igneous or aqueo-igneous origin which occurs as a dike, segregation mass, or inclusion within or without its parent body.

[4] The pegmatite, silexite, and aplite of the region are discussed by the writer in JOUR. GEOL., Vol. 27, 1919, pp. 28–54.

granite and its pegmatitic facies, especially the latter. Injection and assimilation of the old gabbro and hornblende gneiss are of particular interest because, as a result of these processes, the hornblende and hypersthene have usually been largely or wholly transformed into green monoclinic pyroxene (mostly diallage) relatively poor in iron with the accompanying separation of magnetite. There are many very fine illustrations of injection gneisses rich in monoclinic pyroxene. In these injection and assimilation gneisses grains of titanite are generally present usually in amounts ranging from ½ to 3 per cent. Also in many places the Lyon Mountain granite (or its pegmatite) is locally notably more basic than normal and contains considerable green pyroxene, this change in composition having resulted from more or less perfect assimilation of portions of gabbro or hornblende gneiss by the granite magma. Because of the development of magnetite as a result of the transformation of hornblende and hypersthene into the monoclinic pyroxene (diallage), the injection or assimilation rocks are commonly distinctly richer in magnetite than either the normal Lyon Mountain granite or the normal gabbro or hornblende gneiss, but in many cases much of the derived magnetite has been carried away in magmatic solution and deposited elsewhere, often in the ore zones (see discussion beyond). Examples of both the injection and assimilation rocks are common in and about most of the iron mining localities.

With the possible exception of some gabbros later than the granites, the only other rocks (not including Pleistocene) of the Lyon Mountain quadrangle are small dikes, mostly diabase, which have been found to cut the ores and associated rocks by sharp contacts in nearly all the mining localities of the region. These are the latest of the Precambrian rocks of the region.

ROCKS ASSOCIATED WITH THE ORES.

At every one of the localities where magnetic iron ore has been mined, and also at every other place where the writer ob-

served magnetite in considerable quantities, the main body of the country rocks is the Lyon Mountain granite. This is true in the face of the fact that the Hawkeye granite is extensively

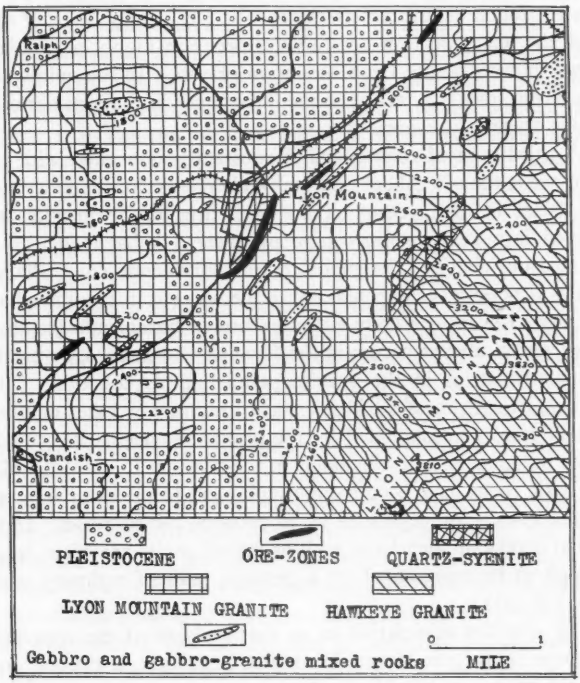


FIG. 36. Geologic map of the vicinity of Lyon Mountain showing the general relation of the magnetic iron ore deposits to the other rocks.

developed and other rocks are locally fairly well developed. The field experience leads to the conclusion that it would be useless to look for workable deposits of magnetite outside the areas of Lyon Mountain granite. The association is so constant as to strongly suggest some sort of genetic relationship between the ore and the Lyon Mountain granite.

Without exception, pegmatite or silexite or both never fail to be closely associated with the magnetite at each of the localities where ore has been taken out. Also at many other places, where magnetite is more or less concentrated, pegmatite or silexite was always found as a direct associate. In fact it may be truly said that the magnetic iron ores always occur in highly pegmatized zones or belts of the Lyon Mountain granite. In the opinion of the writer, this is a fact of prime importance in the consideration of the origin of the ores.

A third type of rock which is constantly associated with the iron ore is the old gabbro or hornblende gneiss (or amphibolite). the latter in many cases having been injected by granite and altered into a green monoclinic pyroxene (diallage) gneiss as pointed out above. The gabbro or the hornblende (or diallage) gneiss is not always in contact with the ore, but in the immediate vicinity of every ore body either gabbro or hornblende (or diallage) gneiss always occurs in the form of lenses, belts, or bands, or narrow strips in the granite parallel to its foliation. The borders of such masses of basic rocks are in many cases more or less injected or assimilated by the granite or pegmatite, and in many other cases, as for example in the mines at Lyon Mountain, the basic rocks have been so thoroughly cut to pieces or injected by the granite or pegmatite as to produce mixed rocks. Individual bodies of such basic rock or mixed gneiss are often large enough to be represented on a geologic map of ordinary scale (see Fig. 36).

The constant association in so many places of the magnetic iron ores with Lyon Mountain granite, pegmatite or silexite, and the old gabbro or hornblende (or pyroxene) gneiss can scarcely be merely a coincidence, and the significance of this association is considered later in the discussion of the origin of the ores.

MODES OF OCCURRENCE AND STRUCTURE OF THE MAGNETITE DEPOSITS.

The quartz syenite, the Hawkeye granite, the Lyon Mountain granite away from the dark gneiss or ore deposits, and the

diabase dikes all contain about normal quantities of magnetite for such rocks and there is nothing of special interest concerning the mode of occurrence of the magnetite in them.

In the Lyon Mountain granite, where it is the country rock of the ore deposits, magnetite is almost invariably visible to the naked eye in the form of tiny scattering grains which constitute usually from ½ to 3 per cent. of the rock. These magnetite grains in thin section under the microscope are seen to vary from anhedral to euhedral, and they mostly or all crystallized during an early stage of the magma consolidation. Close to either the ore bodies or the old basic rocks, the granite is in many cases appreciably richer in magnetite probably due to absorption of magnetite into the granite magma not long before its final consolidation.

In the typical older gabbro and its hornblende gneiss or amphibolite facies, where not affected by the granite or pegmatite, magnetite grains, representing an early stage of crystallization, generally range in amount from 1 to 10 per cent. Where this older gabbro or its hornblende gneiss facies has been more or less injected or assimilated by granite or pegmatite, the percentage of magnetite is generally higher, and in thin section much of the magnetite is seen to be of distinctly late development not only because it very irregularly occupies spaces between the other minerals, but also because it fills cracks in those minerals (see Plate XXIV.). This is eminently the case in the true injection or assimilation gneisses in which, as is pointed out beyond, much of the magnetite of late development is considered to have been derived from the old basic rocks chiefly as a product of the transformation of the hypersthene and hornblende into monoclinic pyroxene (mostly diallage).

What appear to be true dikes of practically pure magnetite on small scales have been observed at a number of places. The most interesting one is not in a mine, but it occurs in a ledge of the old gabbro within a few rods of the Lyon Mountain granite one mile northwest of Moffitsville. This dike, which is one half to one inch wide, sharply cuts the gabbro for at least 15 feet, and

it is roughly bordered by crystals of hornblende. In and about the mines of the Lyon Mountain quadrangle, a number of small apparently true dikes of magnetite have been noted. An excellent example is shown in a specimen which was taken from the old ore dump one mile northeast of Lyon Mountain village. This dike, which is two inches wide with very fine-grained chilled borders, lies in sharp contact with Lyon Mountain granite which is fine-grained on one side and medium-grained on the other. The interior of the dike is fine- to medium-grained. Throughout the dike there are many sharply defined elliptical to lens-like masses of pink potash feldspar up to three fourths of an inch long arranged rudely parallel to the walls of the dike. These are either inclusions or products of early crystallization of the dike material. One rounded mass an inch across of a granular mixture of green monoclinic pyroxene and magnetite with not very sharp boundaries also lies within the dike. It is either an inclusion or a segregation mass. The significance of the dikes of magnetite is considered beyond in the discussion of the origin of the ores.

The later pegmatite and silexite, which usually exist in the form of rather distinct dikes, in many cases contain from 10 to 40 per cent. of magnetite in pure irregular masses from one half of an inch to several inches across. Fine illustrations among many others are the pegmatite dikes on Elbow hill two miles east-northeast of Lyon Mountain village; on the ridge one and one half miles northeast of Standish; and on a little hill one mile east-northeast of Goldsmith.

In regard to the modes of occurrence of the magnetite, the ore bodies themselves are of chief interest. No one word will describe the shape of the ore deposits. They are certainly neither true veins nor beds. Practically all of them may, as Newland[5] says of the deposits at and near Lyon Mountain, "be described as impregnated zones in the country rock of the region." In a broad way the ore bodies may be regarded as of sheet-like or lens-like form, though there are so many local variations and

[5] D. H. Newland, N. Y. State Mus. Bul. 102, 1906, p. 91.

irregularities that even such appellations are in some cases not very appropriate.

The ore zone or belt at Lyon Mountain village is definitely known to be fully two thirds of a mile long as proved by the mine workings. As stated by Newland, a belt nearly five miles long extending from the old Parker mine northeast of Lyon Mountain village, through the Williams mine, the main workings at the village, and to the old Standish mine southwest of the village, is rich in ore. In fact, as shown by magnetic survey, it probably contains more good ore than any other belt in the whole region under discussion in this paper. But the writer does not consider this Lyon Mountain belt to be a single uninterrupted body of ore. Thus the ore of the main workings and that of the Williams mine are thought to represent separate ore bodies, first, because these two rich ore zones show notably different strikes and, second, because the main workings ore is very low in phosphorus while the Williams ore contains a notable percentage. Between these two ore bodies there may be local enrichments in one or more zones, thus leading some to the conclusion that the ore is a perfectly continuous body.

Again, the ore of the Standish mine and that of the main workings are clearly not on the same strike, and a considerable body of relatively barren rock lies between them. Newland has suggested that these two ore bodies are separated by a fault, but the writer strongly inclines to the view that they are now and always have been separate, representing originally distinctly different zones of ore-impregnated country rock. This latter view is in harmony with the hypothesis of the origin of the ore explained below. The statements just made regarding the ore bodies at and near Lyon Mountain village are believed to illustrate in principle an important feature of the ore deposits throughout the region under consideration.

The rock impregnated with ore may be the old gabbro or its hornblende gneiss facies, or the Lyon Mountain granite, or a pegmatitic or silexitic facies of the granite, or the mixed rock which has so commonly resulted from the injection or assimilation of

the old gabbro or hornblende gneiss by the granite or its pegmatitic facies. Of these the pegmatitic and silexitic facies of the Lyon Mountain granite furnish the richest ores. In and about all of the mines of the whole district all of these rock types are so closely associated or intricately involved as to render it necessary to designate such areas on the geologic map as "mixed rocks."

A very persistent feature of the ore zones is their parallelism to the foliation of the country rocks, especially the Lyon Mountain granite. That is to say, the ore zones, belts of old gabbro or hornblende (or pyroxene) gneiss, zones of injection or assimilation gneiss, and the zones of pegmatization (except the latest pegmatites) almost invariably show the same strike and dip as the enclosing Lyon Mountain granite. The only known exceptions are very local ones within or close to the ore zones. This parallelism of ore zones and country rock is an important consideration in the interpretation of the structures and origin of the ore deposits.

The dip of the ore zones is generally high, rarely being less than 40 degrees and varying from that to vertical. So far as could be determined the strikes of the ore zones, with few exceptions, vary from straight to slightly curved, though within the ore zones the ores and associated rocks in some cases show notable variations in dip and strike.

The writer has not been able to find positive evidence for severe compression of the region after the intrusion of the Lyon Mountain granite and its pegmatitic satellites and the deposition of the ore. This view is opposed to the one commonly held. The only very notable example of folding observed by the writer is toward the southwestern end of the main workings at Lyon Mountain village where, as stated by Newland,[6] "the strike changes rather abruptly to east and west, due to a fold, while the dip swings around from northwest to north and becomes considerably flatter. This change is accompanied by crumpling and minor folding in the deposit." According to the present writer

[6] D. H. Newland, N. Y. State Mus. Bul. 102, 1906, p. 91.

even such foldings, which are rare, are reasonably to be explained as due to moderate differential pressure (probably shouldering pressure) upon the granite magma and its earlier developing pegmatites before final consolidation of the whole mass. Strongly supporting this view is the fact that the latest pegmatite dikes, which were intruded after complete or nearly complete soldification of the great body of magma and development of the ore zones, are little or not at all affected by folding. Minor folding or crumpling is not common in the district, and it is nearly always best shown where masses of the old dark gneiss were badly cut to pieces by the invading granite magma.[7]

Another fact which should be emphasized is the general lack of anything like sharp contacts of the ore bodies against the country rock. In many places, as Newland[8] says, "stringers and disseminations of magnetite extend into the gneiss some distance, forming zones of lean ore on either side of the main bodies." Very locally, within or close to the ore zones, sharp contacts of bands of rich ore against granite or pegmatite may be observed. Such occurrences of magnetite appear to be of the nature of dikes (see description above), in some cases with inclusions of pegmatite or granite in them. Diabase dikes sharply cut the ores at almost every mining locality, but such contacts are of no special significance because these dikes are much later than the ore or any of its other asscciated rocks.

Excellent examples illustrating the main principles of ore occurrences as above mentioned are afforded by the main workings at Lyon Mountain village, the Standish mine, and the Bowen and Signor mine near Redford. These will now be briefly described.

The main workings ore belt at Lyon Mountain village really consists, at and near the surface, of two or possibly three rather distinctly separate sheets of ore which occupy different zones not far apart in the country rock. These ore zones vary greatly in

[7] In this connection see the writer's paper in *Jour. Geol.*, Vol. 24, 1916, especially pp. 600-612.

[8] D. H. Newland, N. Y. State Mus. Bul. 119, 1908, p. 113.

thickness from a few feet to 100 feet or more along the strike at the surface as is well shown toward the western end of the main workings. At the surface along the line of the main workings (two thirds of a mile) the ore zones show a slightly curving strike north-northeast by south-southwest, changing rather sharply at the south to nearly east and west. This sharp change in strike appears to be rather exceptional in the region under discussion in this paper. The dip at the surface varies from about 40 degrees to 60 degrees to the northwest. The No. 4 slope or working has been carried down over 2,000 feet along the dip or slope, or over 1,000 feet vertically. The dip changes from about 45 degrees most of the way down to only 10 degrees or less at the bottom where horizontal drifts across the ore body are several hundred feet wide. Such wide drifts may be partly explained as due to diminution of dip of the ore body there, but the thickness of the ore at the bottom of no. 4 is certainly at least 100 feet while it is only about 20 feet at the surface. It may be, as Newland suggests, that the two or three surface ore zones converge in depth. But it is also possible that the great thickness of the ore at the bottom of no. 4 may simply represent a local exceptionally wide single ore zone. Anything like sharply defined walls of the ore bodies in the main workings are rare if present at all. The ores are commonly more or less intricately involved with old gabbro or hornblende gneiss (now mostly changed to pyroxene gneiss), Lyon Mountain granite, pegmatites of earlier and later generations, and injection or assimilation gneisses. Plate XXIII. gives a fair idea of the relationships. Also the strike and dip of the main workings ore zone are perfectly parallel to the strike and dip of the country rock.

In the old Standish or no. 81 mine two miles southwest of Lyon Mountain village, so far as could be observed in the two drifts, the relation of the ore to the country rock is relatively simple. The ore body, which has been mined along its course for about one fifth of a mile, shows a rather persistent thickness of 15 to 20 feet, with strike north 45 degrees east and dip practically vertical. Both strike and dip are parallel to the foliation

of the country rock which is Lyon Mountain granite. Gradation into the country or wall rock generally takes place within a foot. The association of rocks with the ore is much as in the main workings in Lyon Mountain village.

In the old Bowen and Signor mine one mile south southwest of Redford an ore zone which strikes north 60 degrees east has been worked for about one half of a mile along its course. As stated by Newland[9] "in 1905 the deposit was tested by diamond drilling, the results of which have shown that it is irregular and pinches in places to a thin seam. Of the 12 holes put down along the strike, ore was found in all but three and the maximum thickness was 22 feet, which was encountered near the central part of the old workings. On the western end, the body apparently is broken up into several parallel bands. The dip estimated from the data obtained in the drill holes ranges from 45 degrees to 65 degrees east, being steepest on the west." A body of lean ore 6 feet thick was also penetrated by the drill. In this mine all the usual types of rocks are closely associated with the ore, and the dip and strike of the ore zone are parallel to the dip and strike of the foliation of the country rock (Lyon Mountain granite) with which the ore is not in sharp contact.

CHARACTER OF THE ORES.

Megascopic Features.—The most typical of the common ores like those mined in the main workings at Lyon Mountain village megascopically consist largely of magnetite, feldspar and quartz. Such ores usually exhibit a crudely developed foliation; their texture is granitoid to moderately porphyritic; and they are usually medium to moderately coarse grained, though they vary from fine to rather coarse grained. In color the feldspar varies from white to light red. The feldspar and quartz are generally roughly about equal in amount, but in some cases the feldspar greatly predominates, while in other cases the quartz greatly predominates over the feldspar, this latter being particularly true of some of the good ores from the Standish mine and from the

[9] D. H. Newland, N. Y. State Mus. Bul. 119, 1908, p. 127.

Bowen and Signor mine near Redford. Ores of the very common kind here described may in fact be regarded as pegmatitic and silexitic facies of the Lyon Mountain granite very rich in magnetite. Ores of this kind which are mined at Lyon Mountain village carry roughly about 40 to 50 per cent. of magnetite corresponding to about 30 to 40 per cent. of iron.

Perhaps the next most common type of ore is, in most respects, similar to the above but it also contains grains or clusters of grains of green monoclinic pyroxene (diallage) more or less irregularly scattered through the mass.

A less common type of ore is a medium to moderately coarse granular mixture of magnetite and green monoclinic pyroxene (diallage), the two being very irregularly mixed. Such ore exists in the form of crudely defined lenses or bands commonly several feet or yards long, and it rarely if ever exhibits foliation. In such masses the relative amounts of magnetite and pyroxene vary greatly. In some cases the masses consist of practically pure granular diallage; a thin section from the main workings at Lyon Mountain village showing: diallage, 97; magnetite, 2; hornblende, ½; quartz, ½; and a very little biotite and zircon.

A type of ore less seldom seen consists of an irregular, medium to moderately coarse, granular mixture of magnetite and hornblende. Good examples occur on the ore dump at the Parker mine northeast of Lyon Mountain village where the ore also shows scattering crystals of apatite visible to the naked eye.

Richest of all the ores are medium to coarse granular masses of pure or nearly pure magnetite. Small amounts of other minerals, especially pyroxene (diallage), are likely to be present. Such ores, though very subordinate in amount, are not uncommonly encountered in the mines at and near Lyon Mountain village, and they also occur in other ore zones of the region. They occur in the form of strips, bands, or crude lenses always parallel to the strike of both country rock and the general ore zone. They range from a few inches long and a fraction of an inch wide (see Plate XXIII.) to some rods long and several feet wide. Some of these very rich ores appear to be true dikes with

rather sharp contacts (see description above), while others not sharply separated from the enclosing rock may be segregation masses.

Still another type of ore which has been mined to some extent is the later pegmatite where it is rich in magnetite. In such ores the magnetite generally exists in the form of medium to coarse granular bunches from a fraction of an inch to several inches across. Such magnetite is irregularly scattered through the pegmatite, in a good many cases constituting from 30 to 60 per cent. of the rock. In addition to the coarse grained feldspar and quartz, coarse green pyroxene or hornblende or both are commonly present, and biotite is not rare. In some cases the magnetite is mixed with little else than coarse pink feldspar. Ores of this coarse pegmatite are occasionally seen mixed with the more typical ores as they go into the crushers at Lyon Mountain.

In some cases the injection or assimilation gneisses, where they are within or very close to the ore zones, carry 10 to 20 per cent. of magnetite in the form of tiny grains rather evenly scattered through the mass. Rocks of this sort may be classed as lean ores.

Microscopic Features.—The microscope shows that the magnetite mostly belongs to a late stage of crystallization of the ore which contains it. This has an important bearing upon the genesis of the ore. A little of the magnetite usually exists in the form of distinct grains with more ore less well defined crystal faces, but most of it either irregularly fills in between the other minerals, chiefly quartz and feldspar, or it fills cracks in the other minerals (see Plate XXIII.) thus demonstrating that the magnetite mostly crystallized very late, this being quite the reverse of the normal order in igneous rocks. In many cases there are long, narrow, irregular, more or less interrupted bands of granular magnetite, in some places cutting across other minerals, and in other places sending off dikelike tongues into the surrounding minerals. Such streaks and tiny dikes of ore very clearly belong to a late generation of crystallization.

A few descriptions of thin sections will serve to make clear the mineral contents of the typical ores, and the relation of the mag-

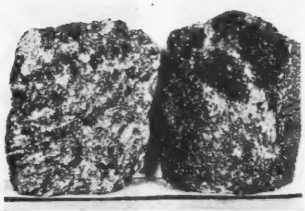
netite to the other minerals. A thin section of typical ore from no. 4 shaft in the main workings at Lyon Mountain shows the following mineral percentages: magnetite, 35; quartz, 25; microperthite, 20; oligoclase, 17; biotite, 2; pyrite, ½; zircon, ¼; epidote, ¼; and very little apatite. The hand specimen shows somewhat more magnetite which in the slide is mostly seen to fill in between the quartz and feldspar very irregularly. In one case it forms a long interrupted band. It seldom shows anything like crystal faces. Strain shadows are strongly developed in the quartz. Some of the microperthite shows the shredded structure beautifully. Most of the biotite is attached to the magnetite usually as partial rims. The pyrite is always attached to the magnetite. The epidote nearly always forms fine granular rims around magnetite or pyrite with oligoclase on the outside of the rims. Granulation of the ore is especially well developed in crudely defined zones or belts.

Another thin section of good ore from the main workings at Lyon Mountain reveals the following mineral percentages: magnetite, 30; quartz, 28; microperthite, 25; oligoclase to albite, 8; orthoclase, 3; microcline, 1; diallage, 4; hornblende, 1½; pyrite, ¼; and zircon, ¼. The microperthite is wonderfully well developed, and the quartz nearly all shows strain shadows under crossed nicols. Most of the magnetite very irregularly fills in between other minerals and it is thus of late development among the minerals of the rock. The diallage shows moderate pleochroism from light green to light yellowish-green, while the pleochroism of the hornblende ranges from bluish-green to green to yellow.

A slide from the best ore of the Clayburg mine on the west bank of the river shows the following mineral percentages: quartz, 46; magnetite, 40; orthoclase, 6; oligoclase, 4; green monoclinic pyroxene (diallage), 4; and a few tiny prisms of zircon. Strain shadows are exhibited by the quartz. The magnetite represents two generations, an early one shown by a few grains with fairly good crystal outlines (some being inclusions in the quartz), and a late one shown by small to large irregular

a.

b.

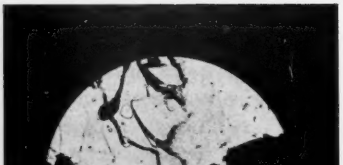


c.

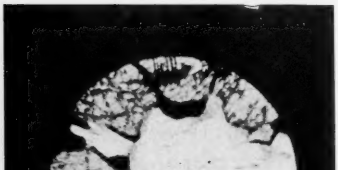
FIG. *a*. View in mine pit at southern end of the main workings at Lyon Mountain. The dark rock is ore cut by granite and pegmatite dikes.

FIG. *b*. Detailed view of ore body in mine pit at southern end of main workings at Lyon Mountain. Magmatic flow-structure foliation is shown; also lens of nearly pure granular magnetite at the middle right. Width of view about four feet.

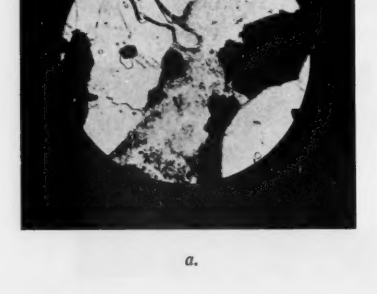
FIG. *c*. Specimen of typical magnetic iron ores from main workings at Lyon Mountain. On left: granular mixture of magnetite, feldspar and quartz. On right: similar but with granular mixture of diallage and magnetite toward top, the whole specimen being cut by pegmatite dikes. Specimens are each 3¼ inches long.



a.



b.



c.

d.

Photomicrographs of magnetic iron ores and associated rocks from the Lyon Mountain quadrangle, N. Y.

FIG. *a*. Magnetite between quartz grains and also filling cracks, wedging it apart. Ordinary light, × 40. From old mine south of Clayburg.

FIG. *b*. Magnetite filling between diallage and feldspar. Ordinary light, × 40. Metagabbro-granite injection gneiss west of Clayburg.

FIG. *c*. Magnetite in granulated matrix of quartz and feldspar. Crossed nicols, × 45. Typical ore from main workings at Lyon Mountain.

FIG. *d*. Hypersthene changing to diallage with separation of magnetite. Feldspar on one side. Crossed nicols, × 45. Metagabbro moderately injected by pegmatite from west of Clayburg.

masses between other minerals or filling cracks in them. In some cases the late magnetite contains inclusions of the other minerals. Plate XXIV. shows magnetite filling cracks in quartz and wedging it apart.

A thin section of lean ore from the Bowen and Signor mine south of Redforth gives the following mineral percentages: oligoclase, 44; quartz, 35; magnetite, 10; hornblende, 5; biotite, 3; microperthite, 1½; titanite, 1½; and very little hematite (stains and specks) and zircon. As usual the quartz exhibits good strain shadows, and the hornblende pleochroism ranges from bluish-green to green to yellow. The magnetite is mostly extremely irregular in shape filling spaces between or cracks in other minerals. The titanite forms narrow rims around some of the grains of magnetite.

	No. 1.	No. 2.	No. 3.	No. 4.
Fe_2O_3	31.480	26.857	56.970	60.128
FeO	15.810	13.628	27.047	28.850
MnO	.115	.103	.111	.107
SiO_2	33.160	36.980	10.000	6.880
Al_2O_3	4.900	6.240	1.360	.900
CaO	4.960	5.800	1.440	.660
MgO	2.100	2.491	.681	.405
P_2O_5	.043	.029	.020	.023
S	.427	.612	.023	.022
TiO_2	.027	.029	.841	.417
FeO (gangue)	2.830	3.214	.129	.257
K_2O	1.438	1.774	.421	.494
Na_2O	2.283	2.152	.848	.777
H_2O	.250	.060	.080	.040
	99.823	99.969	99.971	99.960
Iron (total)	36.500	31.897	61.015	64.720
Iron (magnetic)	34.300	29.398	60.915	64.530
Phosphorus	.019	.013	.009	.010
Manganese	.089	.080	.086	.083
Titanium	.256	.367	.504	.250

A specimen of lean ore from the Standish mine shows the following minerals in thin section quartz, 54; oligoclase, 30; magnetite, 15; chlorite, ½; and very little zircon and epidote. Here again the quartz mostly exhibits wavy extinction, and the magnetite is clearly of very late origin filling in and around the other minerals.

Chemical Composition.—In January, 1919, Mr. George Bent, manager of the Chateaugay Ore and Iron Company, kindly furnished the following chemical analyses of crude ore and concentrates from the main workings at Lyon Mountain village. Nos. 1 and 2 represent analyses of typical crude ores, and nos. 3 and 4 of concentrates.

Because of the very low content each of sulphur, phosphorus and titanium, the concentrates are of high grade Bessemer quality. The titanium is probably all contained in titanite which commonly occurs in small quantities in the ores and more abundantly in certain of the closely associated rocks.

GENESIS OF THE ORES AND THEIR STRUCTURES.

Statement of the Hypothesis.—1. The constant association of the magnetic iron ores with Lyon Mountain granite, pegmatite, silexite and the older gabbro and hornblende or pyroxene gneiss (the last named being probably mostly meta-gabbro) is believed to be very significant as regards the origin of the ores.

2. The older dark rocks gabbro and hornblende gneiss or meta-gabbro) were intruded and so badly cut to pieces by the granite and its pegmatitic facies that the granite, locally altered in composition, now greatly predominates as the country rock.

3. During the intrusion of the granite magma, and more particularly during its long period of crystallization, gases, hot vapors and fluids (probably mostly water) concentrated locally in residual portions of the magma in thousands of places throughout the solidifying granite body. These residual portions of the magma, highly charged with gases or fluids, began to solidify to form the pegmatites and silexites which are now so abundant in many parts of the great body of Lyon Mountain granite.

4. Both pegmatite and silexite began to develop, probably as segregation masses, while the granite magma still possessed a very considerable degree of fluidity, and they continued to form, probably both as segregation products and as dikes, until the enclosing granite almost or possibly completely solidified. The earlier developed pegmatite and silexite masses are now in the

form of either crude bands or zones which mostly rather closely conform to the magmatic flow-structure foliation of the granite, or they are in the form of inclusions, ranging from lenslike to very irregular shapes, being portions of segregations or zones which were pulled apart by the flowing magma and left mostly with long axes parallel to the foliation of the granite. The later pegmatites and silexites are more in the form of true dikes in many cases with rather sharply defined walls and in many cases without sharp contacts. They developed or were intruded during a late stage of magma consolidation and probably in part even after complete solidification of the granite.

5. The residual pegmatitic and silexitic portions of the granite magma, being very mobile on account of their richness in gases and fluids and also being under considerable pressure (probably mostly the shouldering pressure of intrusion), possessed a great power to diffuse into and more or less intimately penetrate the country rock which, in the iron ore localities, was mostly or wholly the old gabbro (usually foliated) or hornblende gneiss (probably also mostly meta-gabbro). Incidentally this explains the fact that the ores are commonly rather intimately involved with old dark rocks (see Fig. 36).

6. The earlier formed residual pegmatitic and silexitic portions of the granite magma, during their penetration of the gabbro and hornblende gneiss, took from them into solution large quantities of magnetite which thus mostly became concentrated in and near those more highly pegmatized portions of the granite body which are more or less intimately associated with the old gabbro or hornblende gneiss.

7. Some of the magnetite taken into solution by the residual portions of the granite magma existed as such in the gabbro and hornblende gneiss, but much of it is believed to have developed as a product of the transformation of hornblende and hypersthene into monoclinic pyroxene (diallage) due to the influence of the pegmatitic and silexitic magmatic solutions. This matter is more fully discussed beyond.

8. Since the general body of granite, more especially its resi-

dual or pegmatitic portions, still possessed a considerable degree of fluidity, and since this magma, being under pressure, was still subject to differential flowage, the magmatic solutions rich in magnetite were forced to higher levels, particularly in those zones where earlier pegmatites and silexites were in varying stages of consolidation and the magmatic solutions flowed in between the already crystallized minerals, chiefly feldspar and quartz, and into cracks in them and there crystallized. Thus we account for the fact that much, if not practically all, of the magnetite belongs to a late generation of crystallization in the ore. In this connection it should be repeated that the most common kind of ore is really a medium to moderately coarse magnetite-rich pegmatitic phase of the Lyon Mountain granite.

9. The crudely developed foliation of the ore is readily accounted for as having resulted from magmatic flowage under pressure during the process of crystallization.[10]

10. The very persistent parallelism of the strike and dip of the ore zones and their foliation to the strike and dip of adjacent granite is likewise interpreted as due to magmatic flowage under pressure. That is to say, both the granite and the pegmatitic ore zone magmas were subjected to the same pressure during the process of crystallization and the magmatic flow-structure foliation of both granite and pegmatitic ore zones are, therefore, essentially parallel.

11. The bands, strips, or lenses of nearly pure magnetite in the ore zones (see above) are probably a result of local magmatic segregation.

12. The medium to coarse granular masses of practically pure green diallage (associated with some magnetite) mostly in the forms of crudely defined lenses or bands (see above), and the granular masses of very irregularly intermixed diallage and magnetite, are quite certainly magmatic segregation products of rather late development, much or all of such diallage having

[10] In a recent paper (*Jour. Geol.*, Vol. 24, 1916, pp. 600–612) the writer has set forth evidence in support of the view that much or all of the foliation of the Adirondack syenite-granite series has resulted essentially from differential magmatic flowage under moderate pressure.

crystallized approximately simultaneously with the magnetite as shown by the general absence of magmatic flow-structure foliation and also by the relation of the diallage to the magnetite. Thin sections of the green diallage rock show 2 to 10 per cent. of magnetite in the form of specks and patches scattered through and between the crystals of diallage.

13. The true dikes of practically pure magnetite with sharp contacts (see above) are probably the result of very late local intrusions of magmatic solutions of magnetite into congealed or almost wholly congealed rocks.

14. Sharp contacts of the ore zones or bodies against the granite would, as a rule, not be expected because the ores are in zones of the general body of granite which became highly pegmatized before complete consolidation of the magma, and so ore zones merge into the granite.

15. Sharp contacts of the ore zones against the old gabbro or hornblende (or pyroxene) gneiss would, as a rule, not be expected because the borders of the larger masses of the old rocks, and the smaller masses entire, were more or less thoroughly injected or assimilate and digested by both the granite magma and its pegmatitic residues, particularly the latter.

16. In those cases where the Lyon Mountain granite adjacent to the ore bodies or the old dark rocks contains considerable magnetite the latter was no doubt absorbed by or forced into the granite while it was still to some extent at least in a magmatic condition.

17. Those latest pegmatites which are more or less rich in magnetite and which are true dikes with rather sharp contacts were intruded into fissures in the nearly or quite consolidated granite-pegmatite body, the magnetite having been absorbed or taken into solution by the pegmatitic fluids from iron-rich rocks penetrated by the pegmatites. The iron-rich rocks are, therefore, in many cases not now adjacent to such pegmatite dikes.

18. The development of the magnetite and its concentration in the ore bodies was a long process, or rather series of processes, which began with the development of early pegmatites and silex-

ites and continued till the late pegmatite dikes were intruded. In other words, the time was nearly or quite as long as that required for the very slow crystallization of the great body of Lyon Mountain granite and its pegmatitic facies.

19. Finally, if the hypothesis here presented essentially accounts for the magnetic iron ores of the Lyon Mountain quadrangle, it is certain that they are not, as has been generally held, products of straight differentiation of a cooling granite magma, though locally it is possible or even probable that some real magmatic differentiation did take place.

Discussion.—In the field the evidence from many localities seems conclusive that the rocks (except gabbro) more or less rich in a diallage which is relatively poor in iron have developed only where the Lyon Mountain granite magma and its pegmatitic facies (chiefly the latter) have injected or assimilated or at least more or less intimately cut the old gabbro or hornblende gneiss. The old gabbro and meta-gabbro always contain much iron-rich hornblende and nearly always considerable hypersthene which is of course an iron-rich pyroxene. In some zones of the injected or only partially assimilated rocks considerable hornblende or hypersthene remain, the transformation of all the hornblende and hypersthene not having been effected. In a good many cases, hornblende has been recrystallized into relatively coarser crystals of hornblende ranging up to more than an inch in length, with no development of monoclinic pyroxene and magnetite. Such recrystallization appears to have taken place where either the injection or assimilation of the old gabbro or meta-gabbro was not so pronounced or where they were intruded by the relatively late pegmatitic fluids which were cooler and less effective chemically. In any case, as may be observed in most of the mining localities, many of the late pegmatites in the form of rather well defined dikes, even where they cut the ore zones, are comparatively free from magnetite, while many of them contain large crystals of recrystallized hornblende.

Microscopic examination of many thin sections also makes it clear that the green diallage has resulted from the transforma-

tion of hornblende and hypersthene, in some cases every stage in the transition being observable in a single slide. Diallage and magnetite are commonly very closely associated in single slides which may or may not also contain hornblende or hypersthene. In some thin sections which show hornblende partly recrystallized into hornblende and partly into diallage and magnetite, the magnetite occurs either as inclusions in the recrystallized larger hornblende crystals or filling cracks in them or in the pyroxene (see Plate XXIV.).

Chemical analyses made for the writer by Miss Hazel Noera, a senior in Smith College, gave the following results. A sample of the typical green granular diallage rock from a large mass at the southern end of the main workings in Lyon Mountain village contains 10.86 per cent. of Fe_2O_3,[11] this representing 7.60 per cent. of iron. A sample of typical slightly gneissoid gabbro from the top of Elbow hill contains 11.54 per cent. of Fe_2O_3, this representing 8.08 per cent. of iron. A thin section of the analyzed green diallage rock contains by volume: diallage, 97; magnetite, 8; hornblende, ½; quartz, ½; and a very little zircon and biotite. The diallage shows excellent cleavages and parting, and pleochroism from light green to yellowish-green and very pale brownish-green. The magnetite is scattered all through the diallage. A thin section of green granular diallage rock from a large mass at the old iron mine 1 mile east-northwest of Riverview contains by volume: diallage, 88: magnetite scattered through the diallage, 10; and quartz as inclusions in the diallage, 2. Neither of these rocks exhibits granulation or foliation. A thin section of the analyzed gabbro contains by volume: labradorite, 45; green hornblende, 30; hypersthene, 21; magnetite, 3; biotite, ½;pyrite, ¼; and a very little zircon and apatite. This specimen of gabbro is from the interior of a mass of the very typical old gabbro where it is unaffected by the granite, but the border of the same mass has been distinctly altered in composition by the granite.

[11] In this and the succeeding case the ferric oxide includes the total iron content of the rock.

Subtracting the iron of the magnetite (3 per cent. by weight) in the diallage rock which was analyzed, the diallage itself really contains only about 5.4 per cent. of iron, corresponding to 8.16 per cent. of Fe_2O_3. In other words it is a green monoclinic pyroxene (diallage) with a relatively low content of iron. It is significant to note in this connection that all the diallage of the injection and assimilation gneisses above described, as well as the diallage of the iron ores, must contain similarly low contents of iron because they are exactly the same optically. Also it should be borne in mind that the analyzed gabbro contains by weight: labradorite, 39; hornblende, 31; hypersthene, 24; magnetite, 5; and a little pyrite and biotite. Thus the 8.08 per cent. of iron shown by the analysis practically all occurs in the three minerals hornblende, hypersthene, and magnetite which make up 60 per cent. of the gabbro rock. In other words, these three minerals contain 12.93 per cent. of iron, corresponding to 18.4 per cent. of Fe_2O_3. After deducting the iron of the magnetite, the hornblende and hypersthene are, therefore, notably richer in iron than the diallage, and much iron oxide must have been set free during the process of transformation of the hornblende and hypersthene into diallage.

Since the transformation of the hornblende and hypersthene into diallage yielded relatively much magnetite, and since such large bodies of injection and assimilation gneisses rich in diallage thus derived occur in and close to all of the ore zones of the district, there seems to be no quantitative difficulty in the way of accepting this explanation for the source of much of the magnetite of the ore bodies. It is significant to note in this connection that in the laboratory "monoclinic pyroxene crystallizes from the liquid obtained by melting hornblende. This is generally accompanied by the separation of magnetite."[12]

Another feature of the above hypothesis which should be enlarged upon is the explanation of the origin of the structures of the ore bodies (see especially points 9 and 10). This is contrary to the view of Newland who, in harmony with certain other

[12] J. P. Iddings, "Rock Minerals," 1911, p. 329.

students of Adirondack geology, maintains that severe compression of the region took place after consolidation of the granite. Thus Newland[13] says: "There can be no doubt that the form assumed by the ore bodies is conditioned by the structures of the enclosing rocks. When the latter are foliated to an extent that permits observations of dip and strike, the contours follow the changes closely, even the subordinate ones. . . . The ores consequently must have been deposited before the great regional disturbances took place, or at least before the rocks received their present structural arrangement. They have passed through all the viscissitudes of squeezing, folding, and other deformations that have been impressed upon their walls." But the writer sees no necessity of invoking severe compression of the region to account for any of the structural or textural features of the ore bodies and their associated rocks. Such features are believed to be more plausibly and simply explained on the basis of the hypothesis set forth in the present paper. Two bits of evidence distinctly opposed to the idea of subsequent severe compression of the ore bodies may here be mentioned. First, the late pegmatites in the form of true dikes represent the latest phase of the granite intrusion, but where such dikes cut through the rocks at various angles they are wholly or almost wholly free from any evidence of ever having been severely compressed. Second, the degree of foliation varies exceedingly within a few feet, even in rocks of like character. A rather elaborate argument against the idea of severe compression of the Adirondack region after intrusion of the syenite-granite series has been presented by the writer in a recent paper.[14] The writer does not, however, object to the conception of moderate pressure upon the granite magma during its intrusion.

[13] D. H. Newland, N. Y. State Mus. Bul. 19, 1908, p. 27.
[14] W. J. Miller, *Jour. Geol.*, Vol. 24, 1916, pp. 600–612.

RELATION OF OIL TO CARBON RATIOS OF PENNSYLVANIAN[1] COALS IN NORTH TEXAS.

MYRON L. FULLER.

INTRODUCTION.

Although it has been known for many years that the distribution of petroleum is intimately related to the degree of chemical change or metamorphism which the containing rocks have undergone, no method for determining the amount of such action, where the change was slight, was proposed until 1915, when David White advanced the hypothesis that the percentage of mixed carbon in pure coals afforded a criterion for measurement.[2]

Dr. White's premises and reasoning have been generally recognized as sound, and the main hypothesis has not been disputed.

Owing to various causes, such as differences in the original sources of the oils, changes due to the filtration incident to migrations, the influence of the composition of the formation containing the oil, the loss of volatile constituents through natural distillation, etc., the subsidiary hypothesis of a direct relationship between carbon ratios and the composition of oils has failed to hold true in many instances, engendering an unwarranted distrust of the more fundamental part of the hypothesis, as a result of which comparatively little application has been made of it in the field.

To date, nevertheless, practically no exception to the general principle of distribution has been developed, and the writer believes that it affords a simple and practically sure method of eliminating regionally unpromising territory.

[1] Ratios in the overlying Cretaceous are all low and favorable to oil, but do not enter into the problem of deep production.

[2] "Some Relations in Origin between Coal and Petroleum," *Washington Acad. of Sci.*, Vol. 6, March 16, 1915, pp. 189–212.

The fact that many of our most prominent geologists are still neglecting the carbon ratios in outlying territory and overlooking its bearing on the presence or absence of oil, is ample justification for the present paper. It is safe to say that in the North Texas field alone not less than 25, and possibly more wells, costing an average of $40,000 each or a total of more than a million dollars, have been sunk within the past year in localities where the carbon ratios are known to be prohibitive.

RELATION OF FIXED CARBON IN COALS TO OIL AND GAS.

General Relations.—In general it has been found that in the oil fields throughout the world the occurrence of 70 per cent. fixed carbon in pure coal (ash and water eliminated) establishes a "dead line" as regards petroleum and natural gas, for although slight accumulations of these products may be found outside of this line, *no instances of commercial deposits are known.*

With lower carbon ratios, oil and gas may be expected, the amount and quality varying with the degree of metamorphism as expressed by the percentage of fixed carbon in coals. For convenience, the relationship is summarized in the following table. While this outline is more specific in its subdivisions than those in the paper of Dr. White,[3] and it embodies statements as to the prevailing characteristic of the sands and water conditions not mentioned by the latter, four years of field application has developed no exceptions, unless it is Healdton field, where the carbon ratio is in doubt.

Relation to Depth.—Carbon percentages increase with depth, but at what rate is as yet unknown. Probably the rate of increase will be variable, being most rapid over or near areas of marked disturbance and least rapid in the broad and deep basins farthest removed from such action.

The rate of downward increase of carbon may, for example, be twice as great in the vicinity of the Wichita and Arbuckle

[3] More specific statements are made in a later paper: "Late Theories Regarding the Origin of Oil," *Bull. Geol. Soc. Am.*, Vol. 28, p. 733, September 30, 1917.

RELATION OF OIL AND GAS TO CARBON IN COAL.

Carbon Ratios (Surface).	Prevailing Characteristics of Sands.	Prevailing Water Conditions (in Mixed Formations).[1]	Production.[2]
Over 70	Hard and tight.	Water usually absent except near surface.	No oil or gas, with rare exceptions.
65–70	Tight, with a few porous spots.	Water usually absent below 1,500 feet.	Usually only "shows" or small pockets. No commercial production.
60–65	Variable, with porous beds of limited extent.	Water usually absent below 2,500 feet (often below 2,000 feet).	Commercial pools rare, but oil exceptionally high grade when found. Gas wells common, but usually isolated rather than in pools.
55–60	Fairly continuous and open.	Water usually absent below 3,000 feet (often below 2,500 feet).	Principal fields of light oils and gas of the world.
50–55	Softer, less firmly consolidated, and more continuous and porous.	Water usually absent below 3,000–3,500 feet.	Principal fields of medium oils of Ohio-Indiana and Mid-Continental fields.
Under 50	Usually unconsolidated and porous throughout.	Sands usually saturated, often with fresh water to all depths reached by wells.	Fields of heavy coastal plain oils and of unconsolidated Tertiary or other formations.

Uplifts of Oklahoma or the Llano Uplift of Texas as in the center of the adjacent Carboniferous basins, or at least will reach prohibitive limits at half the depth.

The indications are that the rise will be at a progressively increasing rate until the "dead line" for oil is reached. At what depth this will be is as yet unknown, but it is probable that it will be much shallower than often believed, possibly in the neighborhood of 4,000–4,500 feet where the surface ratios of fixed carbon are 55 to 60. With lower surface ratios the depth should be greater, but it is very improbable that oil will be found in paying quantities at depths of 6,000 to 10,000 as has frequently been predicted by oil men, no matter how favorable the character of

[1] Unusually porous sands like the Dakota of the West and the St. Peter of the East carry water in quantities far above the average and to far greater depths and distances from the outcrops.

[2] Statements of quality apply to oils from sandstones; oils from limestones are usually considerably heavier.

the rocks and the structure may be, except possibly in unconsolidated or slightly consolidated deposits.

The difficulty in recognizing coal where standard drilling methods are used and the still greater difficulty in securing samples has been supposed to stand in the way of the easy determination of carbon ratios in wells, but if it prove to be practicable to make the determinations on carbonaceous shales, as has recently been claimed,[4] it will be a comparatively easy matter to determine the increase of carbon ratios with depth from the drill cuttings. While in new territory, the geologist will nearly always have to depend on surface ratios as a basis of predictions, the underground data will be of the greatest value in assisting him to a better insight into the problems of deep production.

APPLICATION OF CARBON RATIOS IN NORTH TEXAS.

Source of Information.—Comparatively few analyses of the coals of north Texas are available, these being mainly by the State Geological Survey, supplemented by a few along the east edge of the field by the United States Geological Survey. The former run consistently about three points lower than the latter, but have been used as the basis of the isovolves on the accompanying map because of their greater number and uniformity of source, the difference, however, being borne in mind in case of all predictions.

The determinations used on accompanying map are as follows:

Montague County,
Bowie 63.

Wise County,
Bridgeport 60.

Parker County,
Millsap 60.

Palo Pinto County,
Strawn 56.

Erath County,
Thurber 60.

Coleman County,
Rockwood 53.
Santa Anna 54.
Waldrip 55.

Jack County,
Jermyn 50.

Young County,
Newcastle 52.

Stephens County,
Crystal Falls 50.

Eastland County,
Strawn 56.

Position of Isovolves.—The 60 per cent. isovolve, accepted as the local "dead line," appears to enter Texas about the middle of

[4] Oral statement by members of U. S. Geological Survey. Later information indicates temporary if not ultimate failure of proposed method.

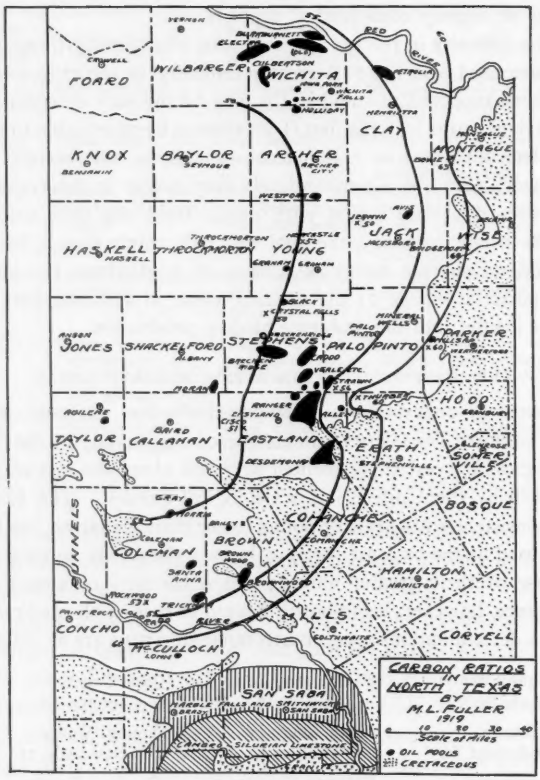


FIG. 37.

the north line of Montague County, and to run south and southwest near and closely parallel to the general margin of the Cretaceous, with a spur or "island" of high carbon near Thurber in northwestern Erath County. The 55 per cent. isovolve extends from near the northwest corner of Clay County southeastward

through Clay, southward through Jack, thence southwestward to the Colorado River in southern Coleman County. The 50 per cent. isovolve is less definitely controlled, but probably runs from northern Archer through Young, Stephens and Eastland, into northern Coleman County.

The high ratio (60 per cent.) at Thurber might be taken as an exception resulting from abnormalities of material or faulty methods of analyses if it were not the fact that it is based on eight analyses and that there are other supporting evidences of abnormal disturbances in the form of the unusually sharp folding, accompanied by faulting, in the vicinity of the Allen wells in northeastern Eastland County, as well as the superior grade of the Allen oil. That the disturbances began at an early date is suggested by the finding of arkose sands in the lower parts of wells near Strawn and on the Allen leases, pointing to the possibility of a pre-Pennsylvanian land mass or "island" near at hand. The reported position of synclinal outliers of Cretaceous suggests that the disturbance has continued down to comparatively recent times.

The high carbon ratio cast of the Carboniferous area, apparently higher than that around the Wichita Mountains on the north or the Central Texas Uplift on the south, is very suggestive and apparently points to an area of high disturbance beneath the Cretaceous immediately east of the margin of the latter. Whether there is an old land mass of pre-Pennsylvanian rocks, an arch of older Pennsylvanian (Bend, etc.) or a series of troughs of the latter between arches of older rocks, is not yet established. Ordovician has been found in wells in Cooke County bordering on the Red River, but apparent Pennsylvanian is encountered at Fort Worth and Dallas. It would therefore appear that pre-Carboniferous rocks, if they occur at all, are limited to a comparatively narrow strip between Millsap and Fort Worth, possibly in the vicinity of Weatherford, but extending indefinitely north and south.

Relation of Oil to Isovolves.—Production from above the 60 per cent. isovolve is limited to a few barrels of high gravity oil

(44 degrees B) in a comparatively shallow sand (2,175 feet) at Millsap, Parker County, and to four or five small wells obtaining equally limited supplies at 225 feet near Lohn, in northern McCulloch County.

Between the 55 and 60 per cent. isovolves are found the Petrolia pool, chiefly gas but with some oil, the Mineral Wells gas pool, and the Brownwood shallow sand pool (200–500 feet).

Between the 50 and 55 per cent. isovolves is found the paying production of north Texas, except that from the Petrolia and Brownwood pools, including the Burkburnett, Electra, Caddo, Breckenridge, Ranger and Desdemona fields.

PREDICTIONS.

If the carbon ratios have the significance assigned them—and as yet there are no important exceptions to the dead line established—oil is not to be expected in paying quantities east of the 60 per cent. isovolve, corresponding roughly in the North Texas field with the Cretaceous margin on the east and with the Colorado River on the south.

The prospects for deep paying production (Bend) between the 55 and 60 isovolves is very small, both because of the high carbon ratio and the regional syncline of Jack, Palo Pinto, Erath and eastern Comanche Counties. The prospects for shallow production (above the Bend) is better, but not distinctly encouraging in this zone.

The prospects between the 50 and 55 per cent. isovolves are excellent for deep (Bend) production where the structure is favorable (as on the "Bend Arch" above the water level). The prospects for shallow production on good local structures are fair, although paying production has not been found on some of the best of the latter, owing to unfavorable water and sand conditions.

PRESENT TENDENCIES IN GEOLOGY: METALLIFEROUS DEPOSITS.[1]

ADOLPH KNOPF.

It is now more than ten years since this society was addressed on the topic of "Present Tendencies in the Study of Ore Deposits." It will give us a convenient starting point if we consider briefly the tendencies in the study of ore deposits that were discerned then by Professor Lindgren. At that time the chief tendencies or problems under investigation were: (1) The increasing use of the microscope in studying ore deposits, and especially the beginning made in applying metallographic methods to the opaque ores; (2) the study of the geographic distribution of metals and their connection with geologic structure, *i.e.*, the study by metallogenetic provinces, a method introduced by De Launay; (3) the attempts to reach a satisfactory genetic classification; (4) the reference of many ore deposits previously held to be of sedimentary origin to the epigenetic class; (5) the study of contact-metamorphic deposits; (6) the recognition of the influence of pressure and temperature in determining the mineral facies of ore deposits; (7) secondary enrichment; and (8) the rapid and widespread acceptance of the doctrine that most ore deposits have originated from magmatic waters.

As we read over the list of the tendencies then apparent, it becomes clear that the intervening years have brought about some decided shifts of emphasis. Some studies, like secondary enrichment, have practically come to a standstill. It is also apparent that some important new tendencies have appeared in the study of ore deposits. Particularly noticeable is the absence from the preceding list of any mention of the influence of geological

[1] Presented before the Geological Society of Washington on May 14, 1919, as the second paper of a series on "Present Tendencies in Geology." Published with the permission of the Director of the U. S. Geological Survey.

thought in molding public policies as to the administration and utilization of mineral resources. This absence is the more noteworthy, for the conservation movement had just then culminated, and the chief ethical basis of this movement, in so far as it is concerned with mineral resources, rests on geologic principles, essentially expressed thus by Van Hise: "The mineral resources took the building of the world for their manufacture. Man had no part in their making; he has added to them in no way. They are part of the heritage of humanity, and succeeding generations are entitled to their share of these benefactions of nature."

Appreciation of the usefulness of the microscope as an instrument of research in the study of ore deposits has not diminished, but a reaction has set in against undue emphasis on its use. It is being clearly recognized that the deeper, more fundamental problems of ore deposition will be solved by field studies, and not by the intensive use of the microscope. This reaction against undue dependence on the miscroscope is voiced most clearly by A. W. Rogers in a notable paper on the copper deposits of Little Namaqualand, Union of South Africa. The ores are mica diorite and norite carrying copper sulphides (chalcopyrite and bornite) and the question is: have the sulphides crystallized from the magma or are they metasomatic? "It is often thought," says Rogers, "that the use of the microscope can decide this question at once, but the result of an examination of some 150 copper-bearing rocks under the microscope in thin section . . . shows that often no definite conclusion can be drawn on such evidence alone. What one sees of the relation between ores and silicates in the ore-bearers proper, *i.e.*, the intrusive rocks which contain copper, can be matched almost completely in the xenoliths of gneiss or schists or in the country within a few feet of the contacts." The decisive evidence for the igneous (orthotectic) origin of the ores is then shown to reside in the field relations. Similarly, Coleman and others dissent from the arbitrament of the microscope, whether it be the petrographic or the metallographic microscope, and appeal to the larger geologic field relations as furnishing the evidence on which the decision must finally rest.

The metallographic microscope has greatly expanded our ideas as to the prevalence of replacement among ore minerals and has thrown much light on similar problems, but it has not altered any fundamental conceptions. Like the petrographic microscope, it is a powerful auxiliary in research, but it is only one of numerous auxiliaries and can not take the place of field investigation.

Another powerful auxiliary is physical chemistry, and the many notable contributions that the Geophysical Laboratory of this city has made along this line are well known. Progress has been somewhat slower, however, than geologists had been led to anticipate. There are, nevertheless, some who believe that all future advance in economic geology will depend on physical chemistry. This appears an extreme belief, in view of the methods that the nature of geologic problems imposes on the physical chemist, namely, the isolation and study of each factor of a problem one by one. After all the factors have thus been separately studied, who will synthesize the results and will the outcome be more successful than it has in other sciences where this method has been tried?

The publication of Lindgren's paper on "The Relations of Ore Deposition to Physical Conditions" in 1909 is a mile-stone in the progress of economic geology. The basal idea of this paper is that certain minerals or groups of minerals are characteristic of the temperature and pressure conditions under which they were formed, and consequently the genetic conditions under which a given ore deposit was formed are ascertainable. This conception dates back at least as far as von Cotta,[2] but it appears to have been allowed to lapse into oblivion, possibly because of Richthofen's severe strictures against it. Later Becke, Van Hise, and Grubenmann, from the study of metamorphism, developed the conception of depth zones each characterized by its own mineral facies. This conception was by analogy applied to the problems of ore deposition by Lindgren.[3] His presentation gained immediate and widespread acceptance and has practically revolution-

[2] "Die Lehre von den Erzlagerstätten," 2d ed., pp. 710–711, 1859.

[3] ECON. GEOL., Vol. 2, p. 754, 1907.

ized the descriptive treatment of ore deposits. It led naturally to the genetic classification of ore deposits that was presented before this Society in 1911 and that forms the theoretical framework of the volume on "Mineral Deposits" published in 1913. The classification differs in an essential way from all previous attempts in that it takes account of the physical as well as the chemical conditions under which mineral deposits have been formed. It assigns fairly precise limits to the ranges of pressure and temperature under which the different types have formed. The classification lacks, however, a suitable terminology, and until this is supplied, the current literature of economic geology will abound in such undesirable expressions as "low-temperature ores," "high-temperature deposits," and the like.

It can be seen now that the doctrine of magmatic waters reached the zenith of its acceptance when the view was advanced that ore deposits, like contact metamorphism, are indubitable manifestations of igneous activity and that therefore in a metalliferous district in which no igneous rocks are exposed, an ore-bringing intrusive must necessarily underlie the district in depth. The presentation of the evidence on the origin of the lead and zinc deposits of Joplin by Siebenthal has contributed powerfully to this result. He has practically proved that cold artesian waters have deposited ore bodies of great commercial importance, the Joplin deposits, after the Silesian, being the largest zinc-lead deposits in the world. This demonstration has served to arrest the extreme acceptance of the magmatic doctrine, and further has had the tendency to redirect attention strongly to the possibility that meteoric waters stimulated by the heat of igneous intrusions may be important vehicles of ore deposition, an alternative view specially emphasized by Lawson. Some objective evidence, often most difficult to obtain, it must be admitted, is now required before specific ore deposits can with confidence be referred as having been formed by magmatic waters, and this new tendency must be welcomed as a return to more rigorous scientific method.

Physiography is being increasingly used in the solution of certain problems of economic geology. It is not a wholly new

development, for more than twenty-five years ago Diller showed how the accumulation of the Tertiary auriferous gravels of the Sierra Nevada was dependent on the development of the peneplain on the range. This conception proved to be particularly useful in deciphering the history and origin of the various gold-bearing gravels of the Klamath Mountains, and Diller has embodied the principle deduced from these studies in the formula that "peneplains are horizons for auriferous gravels." This principle has been found by Brooks to be of much service in the study of the Alaskan auriferous deposits.

Physiography has been of use in estimating the probable depth at which certain ore deposits were formed, and it has been applied in studies of chalcocite enrichment by Tolman, Atwood, and Spencer. In 1907 the relation of the lateritic iron ores of Cuba to the physiographic development of the region was outlined by Spencer. Recently the hypothesis has been proposed by Hewett that the manganese deposits of the southern Appalachian region were formed by meteoric waters during the development of a peneplain of early Tertiary age, or during the initial stages of the subsequent dissection of this peneplain; from which it follows that the manganese deposits are hypsometrically related in their occurrence to the peneplain surface. Such a hypothesis forms a rational guide in the search for undiscovered deposits.

Lately W. M. Davis has discussed the origin of the nickel-bearing laterite of New Caledonia, which is derived from serpentine as a result of surface enrichment by leaching and concentration, and has shown its relation to the later stages of peneplanation and the new cycle of erosion initiated by uplift of the island. From these examples cited it appears that a considerable impetus has been given to the application of physiography to economic geology and that so far the problems attacked deal largely with the origin of gold, iron, manganese, and nickel deposits in relation to the development of peneplains.

So far we have considered only the customary or conventional content of economic geology. There is at present, however, a strong tendency to bring the subject into closer touch with eco-

nomics and with the larger social policies of the State. This latter tendency, foreshadowed during the conservation movement, is most clearly evident in the writings of George Otis Smith and C. K. Leith.

The war and the problems arising from the war as to the international adjustment of mineral supplies have brought to the fore the quantitative estimation of mineral resources. It can not justly be said that before the war geologists had not been interested in the problems of ore reserves; for it was geologists who, before the war, had the world-vision to make inventories of the world's two principal mineral resources—coal and iron. But the war has focused attention upon the desirability of quantitative information as to the world's reserves of other mineral commodities. Some may be sceptical as to the practical value that may flow from such attempts, but it is easy to cite examples where important practical consequences have resulted. The inventory of the world's iron resources by the International Congress of Geologists in 1910 was undertaken on the initiative of Sweden, a country that appears to have been one of the first to deal with its mineral resources systematically with far-ranging prevision. Iron is by far the most important of Sweden's mineral resources and, as Sweden possesses in the Kiruna deposit the largest bodies of high-grade iron ore now being worked, it was of importance to her to know what relation the reserves of that deposit bore to the reserves of the rest of the world. Sweden believed that in this supply of iron ore she had a very considerable fraction of the world's high-grade iron ores, and it was therefore of practical concern to her to limit their export, first because of nationalistic sentiment, which desired to safeguard the home iron industry; and second because with the flow of time the ores would of course increase immensely in value in the world market. However, when the results of the inventory of the world's iron resources become available, it was at once apparent that Sweden's proportion of the world's iron resources was far less than she had believed. Consequently, it could not be expected that the iron ores would increase in value in the near future as much or as rapidly

as had been thought. Further, the inventory showed that Sweden's resources were so large that her iron-smelting industry was in no danger from exhaustion of the domestic supply of ore. As a result of these showings, which succeeded in appeasing nationalistic sentiment, and also because the State needed more revenue, the export regulations were revised and a far larger amount of iron ore was permitted to be exported annually. This, then, was a practical outcome of national and international importance that resulted directly from the stock-taking of the world's iron ore resources.

One of the earliest attempts to estimate mineral reserves by methods other than those of the engineer was that made in 1897 by Verbeek of the geologic staff of the Netherlands East Indies. He estimated the tin reserves of the island of Billiton by the use of a factor, or coefficient, obtained from data afforded by the island of Banca. The method in short was to divide the total tin content of the placer deposits on Banca by the number of square kilometers comprising the area of the island. The factor thus obtained was multiplied by the area of the island of Billiton and gave an estimate of its tin resources. As tested in the light of experience the results can not be considered to have been fortunate, as the subsequent output has far exceeded the reserve estimated.

A similar method was used in 1910 by the Swedish geologist Sjögren in estimating the iron resources of continents for which no quantitative data were available. He obtained a factor, or "iron coefficient" as he termed it, by dividing the known iron ore resources of the comparatively well-investigated portion of the world by the number of square miles in which they occurred and multiplied this coefficient—about 1,790 tons of ore per square mile—by the area of the continents whose resources were to be determined. This method, termed by Eckel the Sjögren method, is used approvingly by Eckel in his treatise on "Iron Ores." Obviously it is a rough method and the probability of the estimates obtained by this method must awaken different degrees of confidence in different minds. Manifestly, if it is at all applicable, it

it more likely to be applicable to iron rather than to such metals as copper or tin. It would seem that the method could be refined by applying geological criteria, and attempts to improve it are worthy of the best efforts of geologists.

An interesting attempt to compute the probable future production of a precious-metal district was made by G. R. Mickle in 1912 in forecasting the future silver output of the Cobalt district, Canada. His article is dressed in a rather formidable mathematical garb; in principle, however, it is comparatively simple, as most of the mathematical reasoning employed is used to evaluate the probable error of the result reached. The method could hardly be used for any other district than Cobalt, where the bulk of silver has come from veins inclosed in a single formation, the area of which is small and definitely known. Most of the silver has been obtained from veins in rocks of the Cobalt series and when the veins penetrate the underlying Keewatin, their silver content gives out. The past output and the degree of exhaustion of the veins being known, it is easy to compute the probable total output. Allowance is then made for the silver content of undiscovered veins, and this amount added to the previous quantity gives the probable total output of the district, which is computed to be 242 million ounces. The probable error of this estimate is shown to be plus or minus 11 per cent., that is, there is an even chance that the output will fall between 215 and 270 million ounces. At the time this estimate was made (in 1912) the output of the Cobalt district had reached 108 million ounces. The output now amounts to 300 million ounces. Consequently, Mickle's estimate is already far under the mark, and it seems likely that Cobalt will produce at least 400 million ounces, instead of the 242 million estimated. The reason for this large underestimate is due to the fact that the calcultaions do not take into account the lower grade ore that can be worked as a result both of metallurgical advances and of the rise in the price of silver. Perhaps this attempt will call to your minds Huxley's famous remarks on mathematical reasoning, or, as more recently phrased by Professor Lindgren, "geologists should be careful how they associate

with mathematicians." There is some danger that geologists, especially those of us who have allowed our mathematics to grow rusty with disuse, will complacently accept these remarks as settling the matter, but the wiser policy is for geologist and mathematician to work in helpful coöperation.

The United States Geological Survey is the largest organization in the world gathering mineral statistics. It has gathered a great store of such statistics, but it is no exaggeration to say that hardly any scientific use of these data has yet been attempted. By the scientific use of statistics is meant the use of statistics as "methods specially adapted to the elucidation of quantitative data affected by a multiplicity of causes."[4]

An extraordinarily suggestive and stimulating example of the use of these methods is furnished by Professor H. L. Moore's book "Economic Cycles: their Law and Cause." His problem was to find the cause of the ebb and flow of economic life, the alternation of periods of great business and industrial activity with periods of depression. He was able to analyze the statistics of rainfall data, crop yield, index number of general prices, and pig-iron production and as a result to formulate the law: "The weather conditions represented by the rainfall in the central part of the United States, and probably in other continental areas, pass through cycles of approximately 33 years and 8 years in duration, causing like cycles in the yield per acre of the crops; these cycles of crops constitute the natural, material current which drags upon its surface the lagging, rhythmically changing values and prices with which the economist is more immediately concerned." It is clear from the method he employs—the statistical method of multiple correlation—that it must prove extremely fruitful if applied to certain geologic problems, which are generally problems of multiple effects.

As a rough beginning along these lines let us take an example nearer home—the persistence of ore in depth. Manifestly this is a problem of multiple effects, for the vertical range of ore deposition is determined by the temperature and concentration of the

[4] Secrist, Horace, "An Introduction to Statistical Methods," p. 8, 1917.

ore-forming solutions, by the pressure prevailing at the time of ore deposition, by the chemical and physical character of the wall rocks, and by other factors. A beginning on the problem has been made by Hoover. Some years ago he made a statistical study of several hundred dividend-paying metal mines in various parts of Australasia, North and South America, England, and Africa, and found that not six per cent. of the mines that yielded profit ever made them from ore mined below 2,000 feet. Of mines that paid dividends, 80 per cent. did not yield a profit below 1,500 feet, and a sad majority died above 500 feet. Now this was an attempt to solve by statistical methods one of the foremost problems in the valuation of mines. Hoover's interest in the problem was that of the engineer appraising a mine for purchase. The problem is becoming of vital interest from a new angle, on account of the increasing tendency of modern states to levy income taxes. In order to assess these taxes equitably, charges for depletion of ore must be allowed, and these involve the matters of ore reserves and the life of the mine. Hoover's solution of this problem is a pioneer attempt and as such is inevitably crude. The problem is essentially geologic and the attempted solution can be greatly improved by selecting the data according to geologic principles, and it is certain that much more important results would thereby be attained. For example, a simple grouping of veins as Tertiary and pre-Tertiary would give a different statistical answer to the problem, for few Tertiary veins are profitable below a depth of 1,000 feet, but the result would be one approximation nearer the ultimate truth. Efforts along this line, according to modern statistical methods, present an attractive field for further research.

It is clear that the wise utilization of the world's mineral resources must rest on an accurate knowledge of the extent of those resources. When this information has been furnished by the geologist, the problem of how best to utilize the resources becomes the problem of the economist and the statesman—of those whose duty it is to formulate and carry out the wider social policies of the State. This being true, it is manifest that increasing

pressure will be brought on geologists for quantitative data as to the world's mineral resources. It therefore behooves geologists to measure up to this opportunity. Appropriate modes of attack on the problem of estimating mineral resources must be developed, which, as I have already indicated, must combine geologic principles with the fruitful methods of statistical analysis.

These are some of the problems that the war has brought into the foreground of attention. If I have dwelt on them at some length it has been without intention of emphasizing them at the expense of the problems of metalliferous geology discussed in the earlier part of this paper. The older problems were necessarily laid aside during the war, but the newer problems are, after all, based upon these older lines of investigation. The war has not altered the fundamental methods of research; indeed, if it were possible, it has deepened our conviction in the inherent supremacy of those methods.

BIBLIOGRAPHY.

Lindgren, Waldemar. Present Tendencies in the Study of Ore Deposits. ECON. GEOL., Vol. 2, pp. 743–762, 1907.

Van Hise, C. R. The Conservation of Natural Resources in the United States, pp. 1–103, 1910.

Rogers, A. W. The Nature of the Copper Deposits of Little Namaqualand. *Geol. Soc. South Africa Proc.*, Vol. 19, pp. xxi–xxxiv, 1917.

Lindgren, Waldemar. Mineral Deposits, 1913.

De Launay, L. Traité de Metallogenie, 1913.

Siebenthal, C. E. Origin of the Zinc and Lead Deposits of the Joplin Region. U. S. Geol. Survey Bull. 606, 1915.

Lawson, A. C. Ore Deposition in and near Intrusive Rocks by Meteoric Water. Univ. California Pub. Dept. Geol., Vol. 8, pp. 219–242, 1914.

Diller, J. S. The Auriferous Gravels of the Trinity River Basin, California. U. S. Geol. Survey Bull. 470, pp. 11–29, 1911.

Ransome, F. L. Geology and Ore Deposits of Goldfield, Nevada. U. S. Geol. Survey Prof. Paper 66, p. 174, 1909.

Emmons, W. H. The Enrichment of Ore Deposits. U. S. Geol. Survey Bull. 625, 1917.

Hewett, D. F. Some Manganese Mines in Virginia and Maryland. U. S. Geol. Survey Bull. 640, pp. 37–71, 1917.

Hewett, D. F., et al. Possibilities for Manganese Ore on Certain Undeveloped Tracts in the Shenandoah Valley, Va. U. S. Geol. Bull. 660, pp. 271–296, 1918.

Davis, W. M. Metalliferous Laterite in New Caledonia. *Nat. Acad. Sci. Proc.*, Vol. 4, pp. 275–280, 1918.

Smith, G. O. The Public Interest in Mineral Resources. U. S. Geol. Survey Mineral Resources, 1915, pt. 1, pp. 1a–9a.

—— The Economic Limits to Domestic Independence in Minerals. U. S. Geol. Survey Mineral Resources, pt. 1, pp. 1a–6a, 1918.

Leith, C. K., in Ely, Hess, Leith, Carver. The Foundations of National Prosperity, pp. 187–272, 1917.

—— International Control of Minerals. U. S. Geol. Survey Mineral Resources 1917, pt. 1, pp. 7a–16a, 1918.

Lindman, A. State Control of Iron Ore Mining in Sweden. *Congrés Geol. International Compt. Rendus,* 11th Session, Vol. 1, pp. 289–296, Stockholm, 1910.

Sjögren, H. Principal Results of the Inquiry on "The Iron Resources of the World." *Congrés Geol. International, Compt. Rendus,* 11th Session, Vol. 1, pp. 297–301, Stockholm, 1910.

Wiessner, Fr. Die Regelung der schwedischen Eisenerz-Ausfuhr und die deutsche Eisenerz-Einfuhr. *Bergw. Mitt.,* Jahrg. 4, pp. 276–285, 1914.

Nicou, P. Les contrats de 1907, 1908, et 1913 entre l'Etat Suedois et les grandes sociétés minères de Gellivare, Grangesberg, et Kiirunavaara. *Soc. L'ind. Minérale de St. Etienne, Bull.,* Vol. 6, pp. 113–135, 1914.

Verbeek, R. D. M. Geologische Beschryving van Bangka en Billiton. *Jaarboek Mijnwesen in Nederlandsch Oost Indie,* Vol. 26, 272 pp., 1897.

Eckel, E. C. Iron Ores, 1914.

Mickle, G. R. The Probable Total Production of Silver from the Cobalt District. *Canadian Min. Inst., Trans.,* Vol. 15, pp. 238–254, 1912.

Hoover, H. C. Principles of Mining, p. 32, 1909.

GENERAL FEATURES OF THE NEW JERSEY GLAUCONITE BEDS.[1]

GEORGE R. MANSFIELD.

The work of which this paper may serve as a preliminary notice, was undertaken shortly before the signing of the armistice as a part of the general exploration of possible sources of potash, a subject of keen interest at that time both to the United States Government and to many individuals.

The New Jersey Department of Conservation and Development, which several years ago took over the functions of the State Geological Survey, shared with the United States Geological Survey the expense of the field work and coöperated to the fullest possible extent in making available its published and unpublished data.

The field work included a number of trips into various parts of the region occupied by glauconite deposits but consisted chiefly in drilling operations, during which 19 holes varying in depth from 9 to 70 feet were sunk, generally into or through the so-called greensand marl beds. The average depth of the holes was 37 feet. Observations were made on the character and thickness of the materials penetrated and samples for analysis were collected. In addition numerous well records were gathered.

The purpose of the work was primarily to obtain quantitative data sufficient to permit tonnage estimates for areas of limited extent, favorably situated for commercial enterprise, and to determine the nature and thickness of the overburden in those areas. Incidentally it was hoped that information bearing on the more strictly geological problems of the greensand might be obtained.

Pending the assemblage of the more specific data it is desirable

[1] Published by permission of the Director of the U. S. Geological Survey; read before the Geological Society of Washington, May 28, 1919.

to emphasize some of the general features of the greensand already known and to mention others that have been brought out in the present study.

Although the mineral glauconite is common in the older rocks in other parts of the country, notably in the Cambrian quartzites of the Black Hills, the Bighorn Mountains, and parts of the Rocky Mountain region, in New Jersey, so far as I am aware, it occurs only in the Cretaceous and later deposits that form the northern part of the great Atlantic Coastal Plain. The coastal plain sediments farther south, even including those of the Gulf Plain, are locally glauconitic, but investigations thus far indicate that the glauconite beds of New Jersey are probably richer in potash than those elsewhere.

In New Jersey the beds in which glauconite is relatively abundant have long been called marl beds. Other beds, calcareous, sandy or clayey, are also included in the term marl as there used. Thus we have greensand or glauconitic marl, clay marl, sand marl, and limesand or limesand marl. Ordinarily greensand is implied when the term marl[2] is used but one or more of the other types is frequently included, especially in well records, so that it is difficult or impossible to make any detailed stratigraphic interpretation of many of these records.

The coastal plain in New Jersey has long been cited as an example of the belted type.

The so-called marl beds lie near or at the top of the infacing slope with a strike of about N. 55° E., and a southeasterly dip estimated by Knapp[3] at 33 feet per mile. Their position is thus relatively near the Delaware River, which occupies much of the inner lowland, and their drainage is in general toward that lowland. Several of the creeks that cross the marl beds, such as Rancocas or Crosswicks Creeks, are large enough to serve if necessary for transportation. However, the presence of large cities, such as Philadelphia, Trenton, New Brunswick and New York along the general line of the inner lowland, and of attrac-

[2] The common term in the literature and usage of the region.

[3] Knapp, G. N., unpublished data.

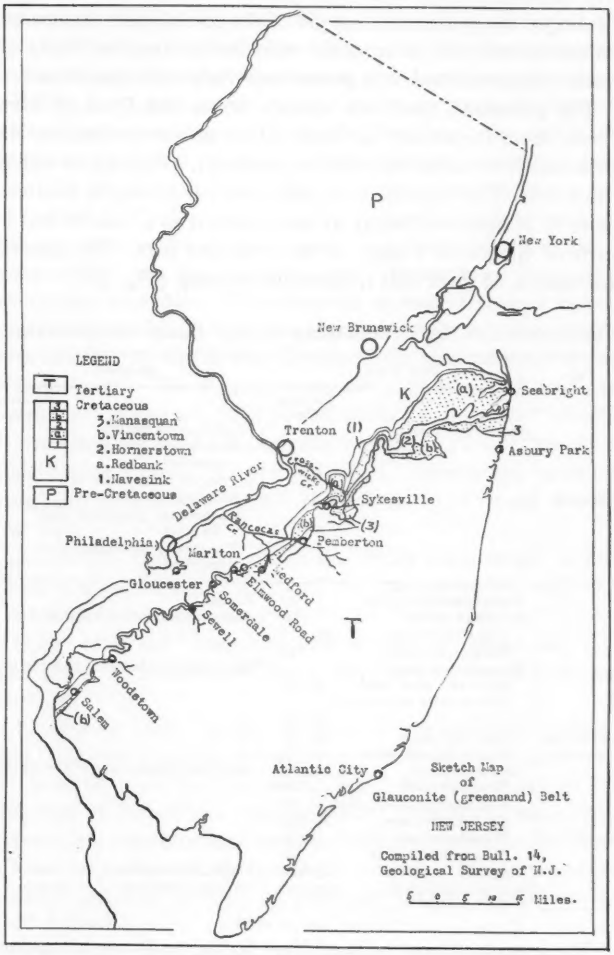

P
New York
New Brunswick
LEGEND
T Tertiary
Cretaceous
3. Manasquan
b. Vincentown
2. Hornerstown
a. Redbank
1. Navesink
K
P Pre-Cretaceous
K
(a)
Seabright
3
(b)
Asbury Park
Trenton (1)
Delaware River
Crosswicks Cr.
(a)
Sykesville
Rancocas Cr.
(b)
(3)
Pemberton
Philadelphia
Marlton
Redford
Elmwood Road
Gloucester
Somerdale
Sewell
T
Woodstown
Salem
(b)
Atlantic City
Sketch Map of Glauconite (greensand) Belt NEW JERSEY
Compiled from Bull. 14, Geological Survey of N.J.
0 5 10 15 Miles.

FIG. 38.

tive seashore resorts such as Atlantic City, Asbury Park and Seabright along the outer margin of the coastal plain has caused numerous railroads to cross the marl belt so that the factor of water transportation has at present relatively small importance.

The greensand marl belt extends across the State of New Jersey from the vicinity of Sandy Hook at the northeast to the Delaware River near Salem at the southwest, a distance of nearly 100 miles. The breadth of the belt varies from nearly fourteen miles in Monmouth County at the northeast to a mile or less in parts of Gloucester County in the southwest part. The general distribution of these beds is shown on the map (Fig. 38).

CRETACEOUS AND EOCENE FORMATIONS IN NEW JERSEY AND MARYLAND.

Age.	New Jersey.	Thickness, Feet.	Maryland.	Thickness, Feet.
Eocene.	Shark river marl	0– 11	Nanjemoy formation:	
			Woodstock greensand marl member	70
			Potapaco clay member	71
			Aquia formation:	
			Paspotansa greensand marl member	47
			Piscataway indurated marl member	69
Upper Cretaceous.	Manasquan formation	25	Absent	
	Rancocas group:		Rancocas formation a few feet	
	Vincentown sand	25– 70		
	Hornstown marl	30		
	Monmouth group:		Monmouth formation 0 (S)–100 (N)	
	Red bank sand, with Tinton sand member at top	0–100 10– 20		
	Navesink marl	25– 40		
	Mount Laurel sand	5– 60		
	Matawan group:		Matawan formation 10 (S)– 50 (N)	
	Wenonah sand	40±		
	Marshalltown formation	35		
	Englishtown sand	20–100		
	Woodbury clay	50		
	Merchantville clay	60		
	Magothy formation	25–175	Magothy formation	0–90
	Raritan formation	150–500	Raritan formation	0–200

The greensand marl beds of New Jersey, with one exception, are of Upper Cretaceous age. The Cretaceous and some of the

Tertiary formations are shown on the accompanying table and the general relationship of the New Jersey section with that of Maryland is also indicated. The Cretaceous beds become thinner southwestward, but the Eocene beds thicken in the same direction.

All the Cretaceous formations in New Jersey above the Raritan are to some extent glauconitic. In the Woodbury clay and Marshalltown formation the greensand is locally abundant and has even been dug for fertilizer. These formations are parts of what was called by Cook[4] the "Clay-Marl series." The formations that are most uniformly glauconitic, and hence most important commercially, are the Navesink marl, Hornerstown marl, and Manasquan formation. The Navesink, 25 to 40 feet thick, corresponds in general to the "Lower Marl" of Cook, although certain beds included by him in that formation are now referred to the Marshalltown. The Hornerstown, about 30 feet thick, and the overlying Vincentown, 25 to 70 feet thick, constitute the "Middle Marl" of Cook. The Manasquan represents two of the three members of Cook's "Upper Marl bed," namely the so-called green and ash marls, which are respectively 13 to 17 and 8 to 12 feet thick.

Above the Manasquan comes the Shark River marl, 11 feet thick, in apparent conformity with the Manasquan but really unconformable. This corresponds to the "blue marl" of Cook's "Upper Marl bed" and is of Eocene age. It occurs only in a few places in Monmouth County and has little commercial importance.

Glauconite occurs locally in some of the overlying Tertiary and Quaternary beds as the result of the erosion and redeposition of material from the Cretaceous beds. At some places, as for example at Somerdale, these reworked glauconite beds overlie Cretaceous greensand beds and may readily be mistaken for them. Closer inspection of the reworked material, however, reveals pebbles scattered through its mass and usually a more or less well defined layer of pebbles at its base.

[4] Cook, G. H., "The Geology of New Jersey," pp. 239–289. Newark, N. J., 1868.

The greensand beds are in general unconsolidated deposits consisting of variable proportions of glauconite, clay, quartz, and probably small fragments of a variety of other minerals. The glauconite grains vary in size from 1/40 to 1/100 of an inch in diameter, according to Ashley's figures.[5] They are green to black in color and impart a greenish tint to beds in which they occur, except that beds consisting largely of dark green or black glauconite appear nearly black when freshly opened. There is much similarity of appearance between masses of the black phase of greensand and masses of disintegrated material from beds of black or brown oölitic phosphate rock from the Idaho field.

Many of the glauconite grains resemble casts of foraminifera, but some are simply rounded and show no definite suggestion of foraminiferal form. Clay with grains of glauconite forms casts of gastropod and pelecypod shells.

Marine shells and other marine fossils representing a considerable fauna have been found in the greensand beds. The shells are scattered to some extent through the mass of the greensand, but there are two beds in which the shells are very abundant and which serve as horizon markers. These are respectively the Belemnitella-bearing bed at the base of the Navesink marl and the Terebratula-bearing bed at the top of the Hornerstown marl.

The basal bed of the Navesink is commonly 2 or 3 feet thick and marked by the presence of the fossil *Belemnitella americana* and by the admixture of considerable quartz sand and gravel with the glauconite. It represents a transition phase between the Mount Laurel and the Navesink and was called by Clark[6] the "sand marl." The gravel grains 1/8 of an inch or less in diameter are smooth or even polished and were called by Knapp[7] "rice gravel." In the central and southwestern parts of the belt

[5] Ashley, G. H., "Notes on the Greensand Deposits of the Eastern United States," Bull. U. S. Geol. Survey, 660, pp. 27–49, p. 30, 1918.

[6] Clark, W. B., "A Preliminary Report on the Cretaceous and Tertiary Formations of New Jersey," Ann. Rept. of the State Geologist for 1892, Pt. II., pp. 169–239, p. 191, 1893.

[7] Knapp, G. N., formerly with the New Jersey State Geological Survey, unpublished data.

this bed is also crowded with shells, including species of *Gryphæa* and *Exogyra,* but farther northeast these shells occur within the body of the glauconite rather than at the base, thus indicating that conditions favorable for the deposition of glauconite began somewhat earlier in the northeastern part of belt than farther southwest.

The shell bed at the top of the Hornerstown marl has a thickness locally as much as 7 feet, of which the upper 2 feet are closely packed with shells of *Terebratula harlani.* The lower portion of the bed contains other shells, a different fauna from that of the Navesink.

The clay, which forms a somewhat variable proportion of the greensand marl, is abundant in certain beds to which it imparts color. Thus some beds are light green, but others are dark green, drab or chocolate brown, though in each bed the glauconite grains are generally dark green or black. The bedding of the greensand, so far as observed, seems relatively uniform and free from cross bedding.

In the northeastern part of the belt in Monmouth County the three principal marl beds are distinct, the Redbank sand separating the Navesink marl from the Hornerstown, and the Vincentown sand separating the Hornerstown from the Manasquan. The presence of all these beds in full development explains the great breadth of the marl belt in Monmouth County.

The Tinton member, which represents the indurated upper portion of the Redbank sand, loses its distinctive character southwestward and the Redbank sand itself becomes indistinguishable near Sykesville in the northern part of Burlington County. Thus southwest of that point the Hornerstown and Navesink marls merge in a single deposit in which both faunas may be recognized, but the respective formations are not clearly differentiated. Similarly the Manasquan marl practically disappears at a point about four miles southwest of Medford in Burlington County. It has been recognized farther southwest in small exposures near Clementon in Camden County and in Swedes Run near Salem. Thus southwest from the vicinity of Marlton in

Burlington County the marl belt includes only the combined bed of Navesink and Hornerstown and the Vincentown sand, which in that portion of the belt is locally quite calcareous.

In the days when Cook wrote his general report on the geology of New Jersey, published in 1868, the marl business was flourishing, marl pits were open and shipping was in progress at many points all along the marl belt. With the introduction of prepared fertilizers and the decline of the marl industry most of the pits were abandoned and became filled with water, swamps and vegetation. The sides or banks have slumped and are now overgrown with brush and trees, some of which have trunks three to six inches in diameter.

At a few pits, notably at Sewell and at Birmingham, digging is in progress or has been within a year or two. These pits give excellent exposures of portions of the beds, but do not afford complete sections. Exposures in road cuts give only partial sections and are seldom fresh. The same statement is true regarding stream valleys, except that the shell beds are locally well exposed in such places and thus furnish definite information about the position of the top or bottom of a bed.

Pleistocene beds overlie the greensand deposits in greater or less thickness almost everywhere and are locally difficult to distinguish from them. Tertiary beds are also present as part of the overburden in many places, as at Sewell. Complete sections of fresh material may be had only by boring. For this work doubtless the auger would suffice at many localities, but at others closely packed gravel and pebbles, loose wet greensand, heavy shell beds or firmly cemented layers offer obstacles that only the drill may overcome.

Borings in the combined Hornerstown and Navesink marls were made at five localities, Salem, Woodstown, Sewell, Somerdale and Elmwood Road (see Fig. 38). The distances between successive localities range from 8 to 12½ miles. At each locality an area 330 feet square and containing 2½ acres was selected. A hole was placed at each end of one side of the square and a third hole as a check at the middle of the opposite side.

Of sixteen holes bored at the five localities named, twelve afford complete sections from the surface through the marl beds.

A comparison of these sections reveals a number of features that bear upon the stratigraphic interpretation of the marl.

Two broad lithologic units are present, an upper formation, predominantly green to greenish black, and a lower formation, brown to brownish black, the so-called "chocolate marl." The contact between the two formations is well defined and usually marked by the presence of sand or gravel grains near the base of the green formation. Locally a water-bearing gravel bed, shells or an indurated layer occur at the contact. This contact would be a convenient lithologic boundary for the Navesink and Hornerstown marls, for which in this portion of the marl belt no definite common boundary is now recognized. A single cast thought by Dr. Stanton to be that of *Cucullea vulgaris,* a wide-ranging form but common in the Hornerstown, was taken from a gravel bed at this contact at Elmwood Road. It suggests that the Hornerstown includes all of the green formation at that locality.

This gravel bed and the sand and gravel grains elsewhere at the contact may represent the southwestern continuation of the Redbank sand.

The Navesink grades downward into the Mount Laurel but appears to rest on a fairly uniform surface at each of the localities drilled, except that at Woodstown and at Sewell variations of about 4 and 5 feet, respectively, in a distance of 330 feet down the dip were observed. These figures would indicate a dip of 64 and 80 feet per mile, respectively, at these localities whereas the average calculated by Knapp, as previously stated, is only 33 feet. This apparently greater local dip may prove to be more widespread or it may indicate local current scour in the Mount Laurel sands previous to the deposition of the Navesink.

On the assumption that the lithologic boundary above suggested is valid the thickness of the Navesink is about 28 feet at Elmwood Road, 23 feet at Somerdale, 17½ feet at Sewell, 14 feet at Woodstown, and 2 feet at Salem, only the sandy basal bed being represented at the last named locality. At Sewell a de-

pression in the top of the formation corresponding to that in which the base lies was observed. At Woodstown a depression of 5 feet was found in a distance of 375 feet along the strike, together with a total observed variation of 9 feet in thickness at the three holes. These features, together with the scant representation of the formation at Salem, may indicate local erosion of the upper beds by current scour or otherwise. On the other hand, at several of the holes the upper beds of the formation show a transition interval of 6 inches to several feet in which streaks of green material are intermingled with the brown.

In general the Navesink marl is more clayey at the top, less clayey and correspondingly more glauconitic in the middle, and more sandy near the base. The less clayey portions slump easily and tend to run like quicksand. At Woodstown a water-bearing gravelly layer was encountered at one of the holes which was not represented at the other two. At Sewell a hard sandy layer with vivianite was found in one of the holes, which did not occur at corresponding depth in the other two, though in these an increasing proportion of quartz sand was noticed. At Somerdale the intermingling of brown and green material was present throughout the formation.

The basal features of the Hornerstown marl have been mentioned in connection with the description of the Navesink.

The top of the formation, as represented by the Terebratula-bearing bed, was found in only one of the holes. Elsewhere portions of the Hornerstown had been eroded. Nevertheless the measurements show that this formation maintains or even increases its thickness toward the southwest. For example, at Elmwood Road, where the Terebratula-bearing bed is present, the thickness is 17 feet 7 inches. At Somerdale the formation is considerably eroded but from 6 to 11 feet remain. At Sewell the maximum thickness measured is nearly 22 feet, at Woodstown 27 feet, and at Salem 21 feet.

In general the Hornerstown marl as observed in these borings is more clayey and lighter in color in the upper part, and more glauconitic and darker colored below. Near the base sand, and

gravel grains and in some places even tiny pebbles appear. Local variations may be noted. For example, at Woodstown, a stony layer about six inches thick occurs at the base in one of the holes but is not found in the other two. Similarly, at Woodstown shells were present at the base in two of the holes and absent in the third. At Sewell a light green, clayey bed four feet thick at one hole is only six inches thick at another 370 feet away. Other variations in color and texture were noted at different localities and at different holes in the same locality.

Three holes were bored in the Manasquan marl near Pemberton. These were not deep enough to penetrate the formation, but they showed some variations in character and thickness of the marl. At the first two holes, which were only 330 feet apart, the uppermost member, a relatively light colored sandy clay with comparatively little glauconite, was three feet thick at the first hole and more than fourteen feet thick at the second. The lower dark green, glauconitic member was more than nine feet thick at the first hole and less than three feet thick at the second. At the third hole, which was nearly a mile and a half away, only the dark greenish member was exposed, more than fifteen feet thick.

These irregularities in the greensand beds suffice to suggest that their accumulation did not take place entirely beyond the range of wave and current action.

Chemical changes are doubtless going on in the marl here and there. At Somerdale, where all three holes were dry irregular streaks of red, brown, or yellow, oxides of iron penetrated the Hornerstown marl to depths of four feet to fourteen feet from the surface. In one hole a yellow powdery clay lay along the base. The intermingling of grayish green and chocolate colored streaks of the supposed Navesink marl was continuous throughout the formation and some of the glauconitic grains had white coatings.

In most of the holes the marl lay beneath the level of ground water. Some layers were relatively impervious but much of the marl was water-bearing. Concretions of clay and marcasite, ferruginous casts and replacements of shells, and nodules of viv-

ianite, indicate some mineralization of the waters in the marl beds. The presence of iron and sulphur in these waters is recognized by their bad taste, and locally by their smell, as attested both by well drillers and by residents. The vivianite, so far as observed, appears to be localized at the base of the Vincentown and Navesink formations.

The glauconite as taken from the borings appears under the hand lens to be relatively fresh but glauconite in positions more exposed to weathering may have supplied some of the iron now in solution in the mineralized waters. Iron may be present in the clay that accompanies the glauconite. Some iron may also have descended from iron-bearing gravels and sands of Pleistocene or earlier age that overlie the bevelled edges of the marl at many places. At Reeves Station a layer of ironstone forms the contact between the Pleistocene beds and the Hornerstown marl. The contact cuts the top of the marl bed at a faint angle and crosses the Terebratula-bearing bed, which is there largely replaced by iron oxide. A subordinate thin layer of ironstone lies within the marl about a foot below the shell bed. A similar ironstone overlies the marl bed here and there at Sewell.

If the decomposition of glauconite has furnished much of the iron in solution it would seem that soluble potash salts might also be found in these waters. The records of the New Jersey Survey do not furnish evidence on this point. Some analyses of these waters are to be made as part of the present investigation.

Variations in the potash content of the marl are probably dependent rather on the relative proportions of glauconite clay and quartz, than upon depletion or enrichment through alteration of the glauconite.

With regard to the possibilities of greensand as a commercial source of potash, the following summary statement may be given. The supply of greensand is abundant. The location of the deposits with respect to manufacturing centers and markets is very favorable. The beds may be mined with dredges or steam shovels. Several processes of extraction have been tried on a semi-commercial scale with some promise of success. Four

companies are now organized for the production of potash from greensand, one of which had a plant in actual operation in March, 1919, at Reeves Station, near Medford. Another plant said to be in operation is located at Gloucester, New Jersey. A third plant, in which large scale production with an attractive by-product is proposed, is now under construction near New Brunswick. The fourth company, which has produced some potash at an old cement plant, now closed, at Stockertown, Pa., plans to construct a new plant about one mile east of Marlton.

DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE MAGMATIC ORIGIN OF BARITE DEPOSITS.[1]

Sir:—Professor Tarr's paper[2] on the Missouri barite deposits and the recent review of his monograph[3] bring prominently forward the question of the origin of such deposits in general, since the author's conclusion, that in Missouri they were formed by ascending hot solutions of deep-seated, presumably magmatic, origin, directly controverts the generally accepted view.

We have long been accustomed to think of barite deposits as belonging to two strongly contrasted types:

1. The widespread occurrence of the mineral in metalliferous veins in many parts of the world in close and obvious connection with igneous rocks. In some of these deposits barite constitutes the bulk of the gangue and may be mined as a by-product, while in others it furnishes the chief value and the ores are by-products. For many years such veins have been generally recognized as of deep-seated origin.

2. Barite in breccias, veins and replacements in many kinds of rocks, especially massive limestones, and in residual soils from such formations, but without apparent relation to igneous activity. Here belong the deposits of Missouri and the Appalachian states. In the absence of known igneous rocks or other recog-

[1] Published with the permission of the State Geologist of New Jersey.

[2] W. A. Tarr, "The Barite Deposits of Missouri," ECON. GEOL., Vol. XIV., pp. 46–67, 1919.

[3] *Idem*, Vol. XIV., pp. 267–269, 1919.

nized evidence as to the mode of their formation, these deposits have been the subject of much speculation, in which it has been generally assumed that they were formed by the circulation of shallow meteoric waters. No particular significance was attached to the presence of the sulphide ores—galena, blends and chalcopyrite—nor even to the occurrence of fluorite, and the origin of these minerals was accounted for by similar hypotheses.

The Missouri barite deposits are in a belt of disturbance that is marked by anticlinal folds, faults, dikes and veins from Missouri to north central New York.[4] Basic dikes cut Ordovician, Silurian and Devonian strata at several places from north central to south central New York; similar dikes intersect the Coal Measures in southwestern Pennsylvania, in both eastern and western Kentucky, and in southern Illinois; and pegmatite occurs in Ordovician strata in central Missouri. In Kentucky and Illinois also occur numerous veins carrying galena, blende, fluorite and barite, both in association with dikes and in many places along this belt where no dikes appear at the surface. The occurrence of blende and galena with the Missouri barite is equally well known.

This curved line of disturbance is roughly parallel to the Appalachian-Ouachita axis of folding. Possibly the Cincinnati geanticline and the Ozark Plateau may owe their origin to the operation of closely related diastrophic and batholithic movements which were concentrated in these regions and of which the veins, dikes, faults and folds in various parts of the belt are but the farthest upreaching manifestations. Similar processes, although not necessarily synchronous, may have operated in the Adirondacks, at the opposite end of the line.

My observations on the occurrence of barite in New Jersey seem to throw some light on the origin of the Appalachian deposits. Pending the completion of a report now in preparation on the ores and minerals of the Triassic belt in New Jersey, the relations can be only briefly outlined here. The deposits were formerly mined near Hopewell, about twelve miles north of

[4] J. H. Gardner, *Bull. Geol. Soc. Am.*, Vol. 26, pp. 477–483, 1915; J. F. Kemp and J. G. Ross, *Annals N. Y. Acad. Sci.*, Vol. 16, pp. 509–518, 1907.

Trenton, where the mineral fills fissures and cements fault-breccia in a plug-like intrusion of diabase which cuts the red Triassic shale near the great Hopewell fault. Smaller amounts of barite occur in fissures and brecciated zones in both shale and diabase at several other localities in the New Jersey Triassic, and its association with the disturbances that marked the closing stages of Triassic time in this region is unmistakable.

Barite deposits also occur in similar faulted zones with or near diabase intrusions in the Triassic shales and sandstones of Massachusetts, Connecticut, Pennsylvania and Virginia—in several places intimately associated with copper, lead and zinc sulphides. Furthermore, the Appalachian deposits in other rocks also occur typically in fissured and brecciated materials with similar mineral associations, in some places with diabase dikes, and in or near normal faults of the Triassic type. Some of these are found in faulted schists and gneisses and some in sedimentary strata of various kinds, but the majority occur in or near massive limestones. Mining has demonstrated the close association of many of the residual deposits in clay with similar veins and breccias in the underlying strata.

The accompanying faults are in striking contrast with the overthrusts that characterized the period of Appalachian folding, and the obvious inference is that the deep fissuring which accompanied and immediately followed the igneous activity of late Triassic brought into play the processes that gave rise to the barite deposits.

J. Volney Lewis.

Rutgers College,
New Brunswick, N. J.

A PUBLICATION FOR GEOLOGICAL ABSTRACTS.

Sir—With the rapidly increasing activity of geological research in all its branches, it becomes more and more difficult for any one student to possess a detailed knowledge of more than two or three branches of the subject. This difficulty is intensified when the student has not an easily available bibliography of the modern

current literature. It is particularly unfortunate that this admission has to be made for our science of geology.

Whilst we may, with more or less satisfaction, consult the files of the International Catalogue of Scientific Literature for non-current literature, yet a compilation of the recent literature on the subject is only to be obtained by a laborious and often time-absorbing search through the files of current journals, *e. g.*, by inspection of the current volumes of *Journal of Geology,* ECONOMIC GEOLOGY, *Geological Magazine, Science Progress,* and a number of continental journals, the student may hope to obtain many references either in list form, or as short reviews, to the various research publications for a given period, in addition to the actual research work published in these journals.

Even after such a compilation, however, he must admit that his collection is anything but complete.

These difficulties of obtaining rapidly all available recent literature, tend therefore to retard the progress of geological knowledge, both by leading to possible duplication of research, and by the non-utilization of valuable data, in subsequent work.

This difficulty has been sorely felt in other departments of science, as mathematics, physics, and chemistry.

The steps taken to overcome this difficulty point the way to a solution for geology.

The case of chemistry is particularly noteworthy. Under the title "Chemical Abstracts" a volume is published fortnightly by the American Chemical Society. This volume aims at presenting a complete list of current chemical literature from all countries, each publication being shortly abstracted.

The chemical investigator is therefore provided fortnightly with a digest of all chemical literature published in a given period. More recently (1918) the science of botany represented by a number of leading American botanists, has launched a monthly volume of "Botanical Abstracts," essentially of the same type as "Chemical Abstracts," *i. e.*, the new journal will be very comprehensive and international in character.

To the writer it seems that the time is now ripe for the launching of a monthly volume of "Geological Abstracts" which will amass all current literature on the many varied and extensive departments of geology.

It would be fitting that this production should have its birth in America, where geology is represented by so many ardent and experienced research workers. If such a compilation is possible in the near future, it would be perhaps advisable to appoint associate editors in extra American countries who could collate the literature published in the lesser known journals of their respective countries. To the writer a model of what "Geological Abstracts" should be is provided in the section "Mineralogical Chemistry" of the "Chemical Abstracts" of the American Chemical Society. May the time be not distant, when through the energies of American geologists, such an abstract of current geological literature will be available to students of geology!

CECIL E. TILLEY.

SYDNEY, AUSTRALIA.

REVIEWS

The Adirondack Graphite Deposits. By HAROLD L. ALLING. New York State Museum, Bulletin No. 199, Albany, 1918.

The graphite deposits of New York, including prospects and abandoned mines, as well as those in active operation at the present time are described in detail and many microscopic and chemical analyses of the ores are given. The author divides the deposits into two groups, those of the northern area where the majority of the deposits are of contact and vein type, and the southern area which is characterized by the bedded form of ore body. The northern area includes the deposits of Essex county particularly a group of prospects and abandoned mines in Ticonderoga Township. In most of these deposits graphite has developed in sedimentary rocks, chiefly limestone, in contact with pegmatite and other igneous rocks. These are too uncertain, too pockety and too limited in extent to be minable under present conditions.

The graphite schists of the southern area are at present the only commercial deposits of the Adirondacks. These are divided into four groups:

1. The normal quartz-schist, with 5 to 7 per cent. graphite, called the Dixon schist by the author, which forms the ore of the deposits which are now being mined. It exists as two beds in some properties, in others as a single bed. This varies in thickness from 3 to 30 feet. The upper and lower layers tend to be micaceous, and as a general rule the mica content increases with increase in feldspar.

2. A feldspar-quartz schist with 6 per cent. of graphite and 10 per cent. of micaceous minerals, called the Bear Pond schist.

3. A phase of the Dixon schist affected by contact metamorphism with development of pyroxene and tourmaline. The graphite has been redistributed and certain layers show an abnormally high content.

4. A meta-arkose or "arkosite" which consists almost entirely of potash feldspar. The author's mineralogical analysis shows 1.6 per cent. of graphite in ore of this type.

Present milling practice makes available as graphite ore only the schist of the first group. The author estimates that the properties of Faxon, Hooper Brothers, the Flake Graphite Company and the Graphite Products Corporation have a collective reserve of from 10,000,000 to

13,000,000 tons of graphite schist, half of which is readily available. A reserve of 5,000,000 tons of available ore with 3 per cent. recoverable graphite would yield 300,000,000 pounds of graphite, enough to maintain the present rate of production for nearly a century.

The schist ores are considered to be of organic origin, the change from organic carbon to graphite having been effected by the heat and pressure accompanying mountain-building stresses. The contact and vein types are considered to be of inorganic origin in that the graphite formed from the breaking up of gaseous oxides of carbon in the pegmatites. The carbon content of the pegmatites may have been derived from underlying sediments containing organic matter.

The author considers that regional metamorphism alone is sufficient to account for the flake graphite content of the schist ores. "The change of organic carbon to crystalline graphite has been affected (effected ?) by the heat and pressure accompanying mountain making stresses, or static metamorphism, causing the volatilization of hydrogen and nitrogen, and the dehydration of the residue, followed by the recrystallization of the amorphous carbon to graphite." While this process is undoubtedly adequate to convert the carbon into amorphous graphite it may be questioned whether the crystallization of the graphite into flakes of commercial size is not principally due to mineralizers accompanying granite intrusion. In the Alabama and Pennsylvania deposits the workable graphitic schists are everywhere intruded by pegmatitic granite and in many places a marked coarsening of the flake is observable near the contacts. Descriptions of other flake deposits, such as those of Texas, Madagascar and Bavaria mention the presence of granite and pegmatite in close association with the workable deposits. In the author's description of the New York schist deposits it is shown that two granite intrusions, one of Laurentian, the other of Algoman age, cut the graphite-bearing series. In his description of the Laurentian granite the author (p. 126) says: "Its universal habit is to be intricately involved with the Grenville series." In many of the descriptions of individual deposits the lit-per-lit injection of this granite into the sediments which contain the graphite bearing beds is particularly noted. The Algoman granite cuts the graphitic rocks in many places near the mines, and this granite is regarded as the active agent in the formation of the contact-metamorphic and vein deposits of the northern area.

In addition to the excellent description of the New York deposits the report contains much of general interest. The method of microscopic analysis developed by the writer is especially valuable. In spite of the necessarily small size of the samples the microscopic analyses check

surprisingly well with the chemical analyses, and yield information as to the type of gangue minerals which is of great value to the miner and which cannot be shown by the chemical analysis.

The milling methods in vogue in the New York mills are described. This subject has however been treated in more detail in a recent publication by Dub.[1] The author follows Bartley[2] in recommending the graphite miners to enter the manufacturing field.

The descriptions are clear and readable and are enriched by well selected illustrations which include maps, cross sections, block diagrams, and camera-lucida drawings of thin sections. It might have been of assistance to the reader if the main features of Adirondack geology had been summarized in a few introductory paragraphs.

HENRY G. FERGUSON.

[1] Dub, George D., "Preparation of Crucible Graphite," Bureau of Mines, War Minerals Investigations Series No. 3, December, 1918.

[2] Bartley, Jonathan, "Can Profits be Made in American Graphite?" *Iron Age*, pp. 86–87, July 8, 1915.

SCIENTIFIC NOTES AND NEWS[1]

SAMUEL J. CAUDILL, geologist and mining engineer with the Gypsy Oil Co., has resigned his position to become Chief Evaluating Engineer for the Marland Refining Co., Ponca City, Okla.

W. A. TARR has returned to the University of Missouri after conducting a party of advanced students in geology and ore deposits on a four months' trip. Detailed studies were made of the lead-copper-cobalt-nickel deposits of Southwestern Missouri, and of selected areas in Colorado.

HORACE B. PATTON has removed his office from his residence at Golden, Colo., to 911 Foster Building, Denver, where he will continue the practice of his profession as geologist, devoting special attention to examination of oil and gas properties, and to ore deposits.

M. Y. WILLIAMS, of the Canadian Geological Survey, and Joseph Keele, of the Mines Branch, are making examinations along the proposed T. & N. O. railway extension north of Cochrane, Ontario.

W. BOYD DAWKINS, emeritus professor of geology in the University of Manchester, has been created a knight.

E. L. PACKARD, professor of geology, University of Oregon, and Richard Nelson, assistant, have been working in western Washington and western Oregon for a California oil company.

WARREN D. SMITH, head of the Department of Geology, University of Oregon, Clarence B. Osborne, of Eaton-Harrison, geologists, Denver, and E. G. Sinclair, of Butte, Montana, have

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

been engaged during the past summer in making extended geological investigations in connection with oil in western Oregon, for the Oregon Bureau of Mines and Geology.

ELLSWORTH Y. DOUGHERTY has been appointed mining geologist in southern Oregon for the Oregon Bureau of Mines and Geology.

H. M. RICHMOND, professor of geology at Williamsville, Liberty, Mo., has been making an examination of the Wyoming Mining Company's mines south of Lander, Wyo.

V. K. TING, director of the Geological Survey of China visited Washington, recently.

RALPH ARNOLD AND FREDERICK G. CLAPP have been appointed on the advisory committee of the International Exposition of Mining Industries.

R. C. ALLEN, Michigan State Geologist, has resigned his office to become Secretary of the Lake Superior Iron Ore Association, with offices at Cleveland.

T. L. WALKER, director of the Royal Ontario Museum of Mineralogy, and mineralogist of Toronto University, is visiting British Columbia.

A. G. BURROWS AND P. E. HOPKINS, of the Ontario Bureau of Mines, have been investigating the districts of Matachewan and West Shining Tree, Ontario.

CARL ZAPFFE, geologist for the Northern Pacific Railway Co., has returned to Brainerd, Minn., from Pierce County, Wash.

CHARLES CAMSELL, of the Canadian Geological Survey, has returned to Vancouver from a trip to Prince Rupert, Alice Arm, and Anyox, where he was planning the work for members of his staff.

GEORGE H. ASHLEY, of the U. S. Geological Survey, has been appointed State Geologist of Pennsylvania.

ADOLPH KNOPF, of the U. S. Geological Survey, has gone to San Francisco after an extended trip to Nevada.

G. B. RICHARDSON has been placed in direct charge of the oil and gas section of the U. S. Geological Survey.

H. C. COOK, of the Canadian Geological Survey, is making an investigation of the Larder Lake gold field of Northern Ontario.

WALTER HARVEY WEED made a professional examination of the Loring district, Nevada, early in September.

RAY J. BARBER is now consulting engineer for the Roxbury Gold Mines, Inc., and is situated in New York City.

REGINALD E. HORE, of Toronto, has been in the Wasapika gold area, examining properties.

D. DALE CONDIT, oil geologist, who has been in the service of the U. S. Geological Survey for several years, has resigned to accept a position with S. Pearson & Sons, Ltd., of London, and has been assigned to work in China and India.

J. H. WINCHELL, JR., of the U. S. Geological Survey, has been transferred from the Washington office to Denver, where he is assistant to C. W. Henderson, chief of the Mineral Resources Division at the Denver office.

HARRY HARPER, mining engineer, of Santiago, Chile, has removed to La Paz, Bolivia, where he is connected with W. R. Grace & Co.

E. J. LAMBERT AND A. J. CARLSON, professors of the University of Minnesota, have completed an examination of the Mesabi and Vermilion ranges in the interest of the Minnesota Tax Commission.

W. C. PHALEN, of the Bureau of Mines, will study magnesite deposits around Quebec. Mr. Phalen expects to be back in Washington shortly.

J. L. Parker has resumed his consulting engineering practice in Vancouver, B. C.

HON. WILLIAM SLOAN, Minister of Mines of British Columbia, was recently in the Portland Canal, Omineca, and Cariboo districts.

F. G. STEVENS, of Toronto, has returned from examining mines in Central America.

COURTENAY DE KALB has gone to Rio Tinto.

R. L. CHASE, of Denver, Colo., has returned from examining properties at Lake City.

THE SEMI-ANNUAL MEETING of the American Institute of Mining and Metallurgical Engineers was held in Chicago from September 22 to 26. The meeting was well attended and a large number of papers were presented. Among those of interest to economic geologists were: "Chrome-Ore Deposits in Cuba, and Manganese Deposits in Cuba," by E. F. Burchard; "Recent Studies of Domestic Chromite Deposits," by J. S. Diller; "Correlation of the Formations of the Huronian Group in Michigan," by R. C. Allen; "Mud Volcanoes in Colombia," by Stanley C. Herold; "Magnesite: its Geology, Products and their Uses," by C. D. Dolman; "Titaniferous Iron Sands of New Zealand," by V. W. Aubel; "Recent Studies of Domestic Manganese Deposits," by E. C. Harder and D. F. Hewett.

THE 22D ANNUAL CONVENTION of the American Mining Congress will be held in St. Louis, November 17 to 21.

ECONOMIC GEOLOGY regrets that labor difficulties encountered by the printer necessitates making this number smaller than customary.